# Noninvasive and Invasive Comprehensive Intelligent Cardiovascular Diseases Diagnosis in e-Home Healthcare

Taichun Tang, Jiali Ma, Mubo Chen, Mingchui Dong, Zhaoxiong Fang, and Lichun Luo

***Abstract*—To release the burden of medical personnel and satisfy users with diversified backgrounds and requirements, a hierarchical intelligent cardiovascular diseases (CVDs) diagnosis system in e-home healthcare is pioneered to perform noninvasive and invasive comprehensive diagnosis with ranked levels and accuracies. As the top-level diagnosis and authoritative reference, the diagnostic results in upstream must be eminently high precise to support functionality of the overall system, yet it is woefully inadequate by only relying on the noninvasive multi-vital-signs employed in lower streams diagnosis. Tackling this, invasive blood test parameters (BTPs) extracted from routine blood test are exploited as complementary. In this paper, an intelligent BTPs diagnosis system is initiated and integrated to the entire e-home healthcare. The dedicated frame-based medical database (DB) and knowledgebase (KB) provide the standard for BTPs related studies. An intelligent inference engine (IE) is constructed to perform integrative seamless diagnosis for home users. Experimental results validate the high performance of the proposed system with averaged diagnostic accuracy of 84.38% for 241 site-sampled CVDs records. With such an organic combination of noninvasive and invasive diagnosis, it provides a solid and reliable mainstay for the functionality of the entire system.**

***Index Terms*—Blood test parameters, e-health, frame shell design, hierarchical diagnosis, knowledge representation, noninvasive and invasive comprehensive diagnosis.**

## I. Introduction

Cardiovascular diseases (CVDs) are the leading cause of fatality throughout the world. As reported by the World Health Organization (WHO), 17.3 million people died of CVDs in 2008, representing 30% of all global deaths and the number is estimated to reach 23.3 million by 2030 [1]. For efficient treatment, early prevention, and proactive detection of CVDs, various e-health applications have been flourishing, such as telemedicine, remote monitoring, and mobile health (m-health) [2]-[4]. By transmitting the acquired signals to medical personnel or predefined doctors' mobile phones to procure the diagnostic results or alarm messages, these e-health services are beneficial for efficient health status monitoring. However, it accordingly brings along increasing burden for the medical professionals by taking care of both on-site and remotely-linked patients. To mitigate this situation as well as satisfy home users with diversified backgrounds and requirements, a hierarchical intelligent diagnosis system in e-home healthcare is pioneered in Fig. 1 to perform noninvasive and invasive comprehensive diagnosis with ranked levels and accuracies [5].

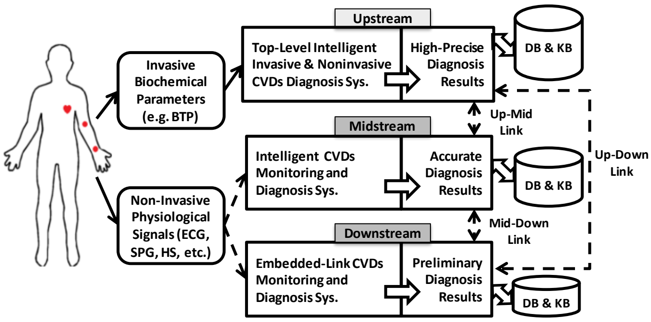



Fig. 1. Framework of the hierarchical intelligent CVDs diagnosis system in e-home healthcare.

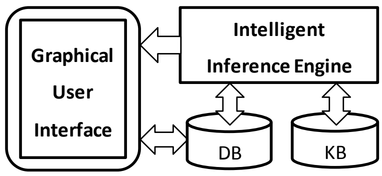



Fig. 2. Intelligent BTPs interpretation system for CVDs diagnosis.

As illustrated in Fig. 1, three entities are concerned in the system, namely upstream (hospital server), midstream (local computers), and down-stream (embedded-link devices, such as smartphone, iPad, Tablet, etc.). The lower streams fulfill local diagnosis based on the acquired biomedical signals automatically without manual intervention and network communication, while the diagnosis conducted in upstream could not be accessed when cable or wireless network is unavailable. The typical workflow is as follows. Firstly, multi-vital-signs such as electrocardiography (ECG), sphygmogram (SPG), or heart sound (HS) are acquired with the aid of body sensor network (BSN). Afterwards, these signals will be transmitted to down- and/or midstream for local interpretation and diagnosis. According to their differences in medical database (DB) and knowledgebase (KB) sizes, downstream serves as the preliminary diagnosis while midstream offers more accurate and thorough diagnosis. However, due to the intrinsic resource restriction of local devices in lower streams facing with hundreds of CVDs, there may occur diagnosis failure or doubt about the diagnostic results. Under these situations, the local devices could ask the upstream for help by sending the acquired signals and related personal information to server in upstream

Manuscript received March 5, 2014; revised May 10, 2014. This work is supported by the Research Committee of University of Macau under Grant MYRG184 (Y2-L3)-FST11-DMC, and Science and Technology Development Fund (FDCT) of Macau S.A.R under Grant 018/2009/A1, respectively.

Taichun Tang is with the Department of Software Engineering, Faculty of Science and Technology, University of Macau, Macau S.A.R., China (e-mail: tangtai009@163.com).

Jiali Ma, Mubo Chen, and Mingchui Dong are with the Department of Electrical and Computer Engineering, Faculty of Science and Technology, University of Macau, Macau S.A.R., China (e-mail: jimohanqiu@hotmail.com, chenmubocs@gmail.com, mcdong@umac.mo).

Zhaoxiong Fang and Lichun Luo are with Shaoshan People's Hospital, Xiangtan, Hunan, China (e-mail: 522706981@qq.com).

DOI: 10.7763/IJBBB.2014.V4.364

if communication network is available. The uplinked server, as the backyard online assistance system, will perform top-level diagnosis to obtain the definitive high precise diagnostic results and feed them to lower stream devices.

Note that the diagnostic results of upstream must be exactly precise to provide absolutely authoritative and eminently trustworthy reference for the overall system. However, only relying on the noninvasive multi-vital-signs with limited information is woefully inadequate to support comprehensive and high precise CVDs diagnosis. Tackling this, invasive blood test parameters (BTPs) extracted from routine blood test are employed as complementary for noninvasive diagnosis in this paper. Since BTPs contain numerous of pathological information that is undetectable in noninvasive biomedical signals, they serve as an important indicator for the major detection of CVDs in hospitals. Based on this, an intelligent BTPs diagnosis (IBD) system is initiated and integrated to entire e-home healthcare as the first attempt among this world so far. With such an organic combination of noninvasive and invasive diagnosis, it could not only effectively guarantee the diagnostic accuracy of upstream, but also provide a solid and reliable mainstay for the functionality of the entire system.

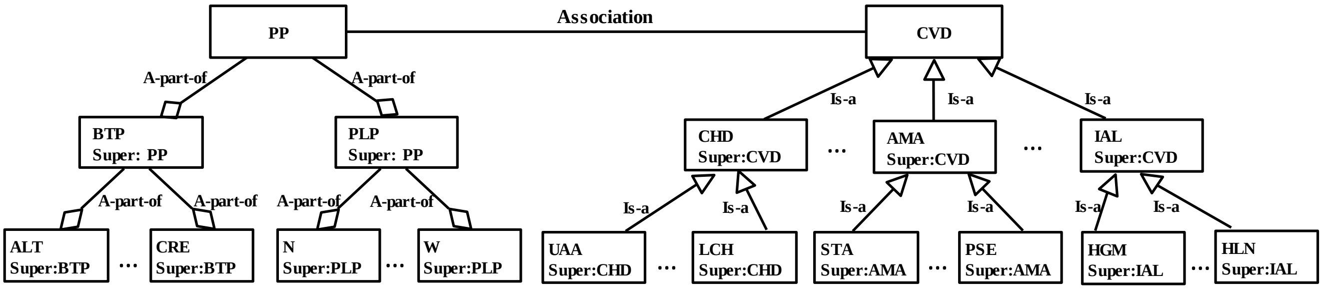



Fig. 3. Frame-based structure of medical DB.

## II. System Architecture

The proposed IBD system for CVDs diagnosis consists of four parts: medical DB, KB, inference engine (IE), and graphical user interface (GUI) as depicted in Fig. 2. At the startup of IBD system, users are required to input the personal information and BTPs values. These parameters will be stored in DB automatically for backup usability. Afterwards, an IE is invoked to perform intelligent analysis and deduction based on the input parameters in DB and the medical diagnostic rules in KB. Finally, the diagnostic results and related warning messages are generated automatically and displayed on GUI. The whole diagnosis process is highly intelligent and automatic triggered by one-click, thus it provides integrative seamless diagnosis for home users.

### A. DB Construction

As foundation of entire IBD system, DB stores user information, BTPs behaviors as well as CVDs details. Several technical requirements should be satisfied when constructing DB: 1) clarity in structural arrangement; 2) consistent in disease representation; 3) extensibility to other unknown diseases; 4) interoperability in various operation platforms. Given this, the frame structure with shell design idea is employed in this paper [6].

TABLE I: Acronym of PPs

| No. | Abb. | Meaning | Father Frame |
|---|---|---|---|
| 1 | N | Name | PLP |
| 2 | A | Age | |
| 3 | H | Height | |
| 4 | W | Weight | |
| 5 | ALT | Alanine transaminase | BTP |
| 6 | AST | Aspartate | |
| … | … | … | |
| 40 | DBP | Diastolic blood pressure | |

TABLE II: The Diverse of Specific CVD

| No. | Abb. | Meaning | Father Frame |
|---|---|---|---|
| 1 | CFN | Cardiovascular function normal | CFN |
| 2 | UAA | Unstable angina | CHD |
| 3 | STE | ST-segment elevation myocardial infarction | |
| … | … | … | |
| 6 | NST | Non-STE | |
| 7 | ASS | Aortic stenosis | VHD |
| … | … | … | |
| 10 | MIC | Mitral incompetence | |
| 11 | SBA | Sinus bradycardia | AMA |
| 12 | ATA | Atrial Tachycardia | |
| 13 | AFN | Atrial fibrillation | |
| … | | … | |
| 17 | PSE | Pre-excitation syndrome | |
| 18 | HMA | Hyperlipidemia | THS |
| … | … | … | |
| 21 | HS1 | Hypertension lever 1 | |
| 22 | HS2 | Hypertension lever 2 | |
| 23 | HS3 | Hypertension lever 3 | |
| 24 | HLK | Hypokalemia | IAL |
| … | … | … | |
| 27 | HHN | Hypernatremia | |

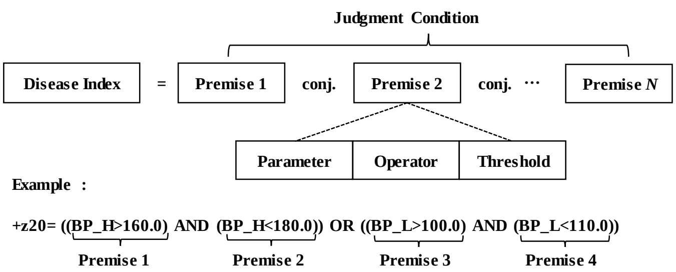



Fig. 4. Fundamental rule structure of medical KB.

TABLE III: Rules Distribution in KB

| CVD | Number of rules | CVD | Number of rules |
|---|---|---|---|
| CHD | 5 | THS | 6 |
| VHD | 4 | IAL | 4 |
| AMA | 7 | ***SUM*** | *26* |

As illustrated in Fig. 3, the designed DB is composed of two classes: personal parameters (PPs) and CVDs. The abbreviations of objects in PPs and CVDs are partially listed in Table I and Table II respectively. Totally 40 PPs including 4 physiological parameters (PLPs) and 36 BTPs are employed, to diagnose 5 typical and frequently encountered types of CVDs and 1 healthy CFN (cardiovascular function normal) status. Both PPs and CVDs are frame-based and can be further divided into three layer frames, namely grand-parent frame, parent frame, and children frame. All contained frames are arranged hierarchically and inherit the attributes of higher frames. Each frame has its own slots describing a particular attribution. The fillers of a slot might be actual data, value ranges, or procedures. For example, the slot fillers of frame "BTPs" are ALT, CRE, and etc.

Besides the objects of frames, there are three types of relationships between frames: 1) generalization, denotes as "is-a" relationship between a superclass and its subclasses, each subclass inherits all features of the superclass; 2) aggregation, denotes as "a-part-of" relationship in which several subclasses representing components are associated with a superclass representing a whole; 3) association, describes some semantic relationships between different classes. It is observed from Fig. 3, the relationships between layered frames in PPs and CVDs are aggregation and generalization separately. Whereas the relationships between frames in PPs and CVDs are associations implying which PPs should be used when inferring what CVDs.

The dedicated frame-based DB structure with reusable shell design could support class inheritance and represent the information in a taxonomic hierarchy manner. It is remarkable that the proposed DB is CVDs oriented while the design methodology is applicable for many other disease representations such as cerebrovascular diseases etc.

## B. KB Construction

Medical DB serves as the data warehouse while medical KB contains all the heuristic rules required for diagnostic inference. Each rule explains the mapping relationship between certain CVDs and related BTPs behaviors. A complete and professional KB is the basis of comprehensive and accurate diagnosis. However, no BTPs rules have been developed so far according to literature survey. In this paper, we refer several medical specialists to extract the BTPs knowledge and represent them as rules with the specialized structure shown in Fig. 4. Fundamentally, a rule is made up of a disease index and a judgment condition consisting one or several premises. Each premise contains a real value of certain BTPs, a threshold value, and an operator between them to compare the two values. Each rule corresponds to a certain disease with a unique disease index number. A rule example is given in Fig. 4, where 4 premises are contained to diagnose the disease HS2 numbered as "z20". In the designed IBD system, a specialized KB of 26 rules is constructed and the distribution of these rules is listed in Table III.

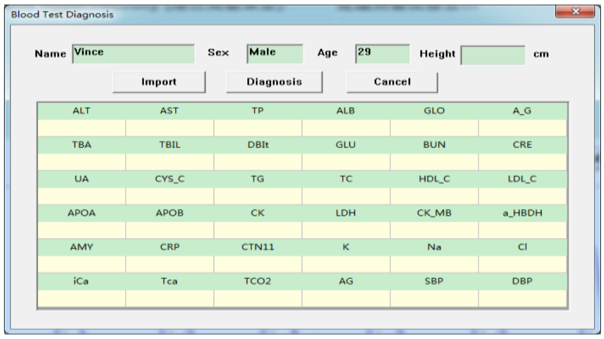
## C. Intelligent Inference Engine

Intelligent IE is the kernel of IBD system [7] to conclude the accurate diagnostic results with detailed explanations and corresponding warning messages based on the existing KB rules and the input BTPs in DB.

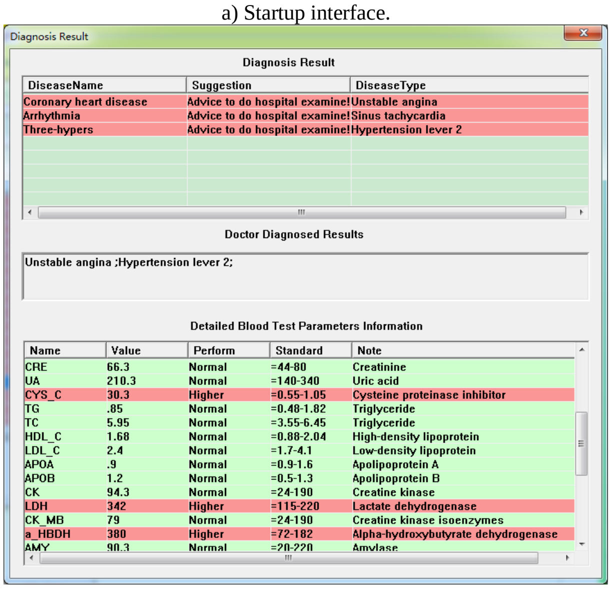
**Algorithm: Interpretation of BTPs**

```
Step 1: system variables statement
  Load R[]     //R[] stores all the BTPs diagnostic rules
  Load WA[]    //WA[] holds all the warning messages
  Load TH[]    //TH[] stores all the threshold values of BTPs

Step 2: patient's variables statement
  Load P []    //P[] holds the input BTPs and physiological
               //parameters for a certain patient
               //input of this algorithm
  int RC[]     //RC[] stores the disease diagnostic rules conclusion
  int DR[]     //DR [] stores the diagnostic results of 27 diseases
               //for the patient, initial value is 0
               //output of this algorithm
  string WM    //WM stores the warning message for the patient
               //output of this algorithm

Step 3: diagnose CVDs from P[]
  For j =1 to R.length()
    RC[j] = R.CalcCondition(TH, P)   //calculate the result
                                     //of j^th rule
    If (RC[j] is true)               //condition is satisfied
      DR[j] = 1                      //the j^th disease is true
      WM += WM[j]                    //add the j^th disease warning
                                     //message to the patient's WM
    End If
  End For
```

Fig. 5. The pseudo code of the inference algorithm.




a) Startup interface.




b) Diagnostic results interface.

Fig. 6. GUI of the designed IBD system.

The pseudo code of the inference algorithm is illustrated in Fig. 4. First, all the system variables in local KB and DB are loaded into IE, including BTPs threshold values and warning messages in DB as well as rules in KB. Afterwards, the patient's input PLPs and BTPs values will be loaded as well. Based on these parameters, the IE will judge the condition of all KB rules one by one. Once the judgment condition of a certain rule is satisfied, the corresponding disease index will be recorded as potential disease. Meanwhile, the pathological warning message corresponding to the disease will be generated as well.

### *D. GUI*

GUI provides the user-friendly link between users and IBD system, such as the interface for user information input, history data access, diagnostic results display and communication between up-down streams etc. Fig. 5 describes the developed GUI for IBD, where Fig. 5 (a) is the startup interface reminding users to input or load personal information and BTPs values, and Fig. 5 (b) displays the diagnostic results with generated warning message for a patient with UAA, STA and HS2. As indicated in the warning message, the parameters of BUN, CRE, CYS_C, TG and TC are beyond the normal ranges and should be checked on a regular basis.

## III. Experimental Results

### *A. Experiment Setup*

To validate the designed IBD system, 241 site-sampled BTPs records from 241 patients with different CVDs are obtained from Shaoshan People's Hospital. Table IV lists the diseases distribution of all the records.

### *B. Performance Measure*

For quantitative judgment and evaluation on diagnosis performance of proposed IBD system, the diagnostic accuracy (*DA*) is introduced as defined in (1):

$$DA(\%) = \frac{N_{equal}}{N_{total}} \times 100\% \quad (1)$$

where $N_{equal}$ is the number of equal diagnostic results between the actual clinical results from medical professionals and experimental results from IBD system, and $N_{equal}$ denotes the total number of CVDs (in this paper $N_{total}$ is 26). Higher *DA* indicates better diagnostic performance and the maximal value of *DA* is 100% which implies that the experimental results are exactly the same with the doctors' clinical results.

### *C. Experimental Results*

TABLE IV: Patients Numbers with Different CVDs

| CVDs | Total Number | CVDs | Total Number |
|---|---|---|---|
| UAA | 80 | AFN | 45 |
| NST | 25 | PSE | 56 |
| STE | 21 | HMA | 55 |
| STA | 58 | HS1 | 72 |
| ASS | 1 | HS2 | 60 |
| AIC | 2 | HS3 | 16 |
| SBA | 47 | HLK | 50 |
| ATA | 67 | HHN | 8 |

By using IBD system, all 241 records are diagnosed automatically. The achieved diagnostic results are recorded and compared with actual doctors' clinical results to obtain the performance index *DA*. The distribution of *DA* for all tested records is plotted in Fig. 6. It is observed that for most of the records, the obtained *DA* value is larger than 80%, an averaged *DA* of 84.38% is achieved. Experimental results validate that the proposed IBD system works well and the achieved performance is adequate for e-home CVDs diagnosis.

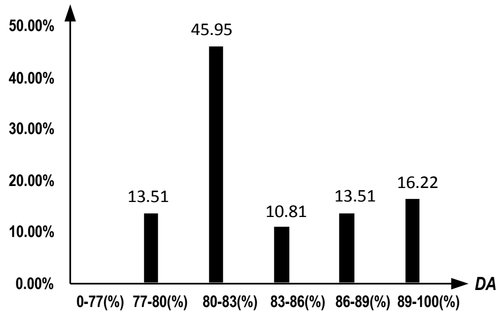



Fig. 7. Distribution of *DA* for different records.

## IV. Conclusion

To guarantee the high precise diagnostic accuracy in top-level upstream of the hierarchical intelligent CVDs diagnosis system, invasive BTPs are introduced as a complementary to the noninvasive multi-vital-signs diagnosis. Based on the dedicated frame-based medical DB and KB, an intelligent BTPs diagnosis system is initiated, in which an IE performs integrative seamless diagnosis and generate automatically the alert messages for home users. Experiments conducted on 241 site-sampled CVDs records verify the high performance of such proposed system.

The future work will be focused on the combination of the proposed IBD system with noninvasive diagnosis system organically.

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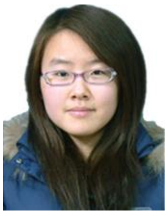
**Taichun Tang** is currently a postgraduate student in software engineering, University of Macau, Macau, China. He received Bachelor degree in computer science and technology in 2012 from Shihezi University, Sinkiang, China. His current research is oriented to R&D 3-Rank CVD intelloigent diagnosis.
His main research interests are machine learning, application of AI in biomedical engineering and similarity and complexity analysis.



**Jiali Ma** received the B.Sc. degree in electrical and information engineering from Tianjin University, Tianjin, China in 2011. Currently, she is pursuing master degree in electrical and computer engineering at University of Macau. Her research interests include biomedical signals compression and construction of embedded-link e-health systems.

**Mubo Chen** is currently pursuing MSc degree in ECE Department of University of Macau, Macau. His current research is oriented to R&D a hybrid intelligent system to diagnose cardiovascular disease. He received bachelor degree in CS in 2012 from Guangdong University of Foreign Studies.

His research interests include machine learning, applying AI technology in various engineering and biomedical applications etc.

**Mingchui Dong** is a full Professor and PhD supervisor of ECE Department of University of Macau, Automation Department of Tsinghua University, China and Professor of YanTai University, China. He received MSc degree in EEE in 1975 at Tsinghua University, China, Visiting Scholar in EEE in 1981 at Rome University, Italy.

His main research interests are AI and its application in biomedical engineering, CIMS, fault diagnosis, AI in vision-to-text, voice-to-text machine translation etc.

**Zhaoxiong Fang** is currently a doctor of the Emergency Department, Shaoshan People's Hospital, Xiangtan, Hunan, China. He received bachelor degree in Department of Clinical Medicine in 2012 from University of South China. His research interests include cardiovascular disease, cerebral vessels disease diagnosis and disease intelligent diagnosis.

**Lichun Luo** is currently the director of the Medicine Department, Shaoshan People's Hospital, Xiangtan, Hunan, China. He is with the Department of Clinical Medicine from Xiangya School of Medicine, Central South University. His research interests include cardiovascular disease, cerebral vessels disease diagnosis and disease intelligent diagnosis.