

Game theory in designing mHealth apps for monitoring hypertension

Antonio CLIM

*The Bucharest University of Economic Studies, Bucharest, Romania
antonio.clim@csie.ase.ro*

Răzvan Daniel ZOTA

*The Bucharest University of Economic Studies, Bucharest, Romania
zota@ase.ro*

Abstract. *The Game Theory model provides revolutionary grounds for tackling problems in an optimal manner by considering various constraints and conditions. This research paper proposes a novel idea of monitoring, diagnosis and treatment of hypertension using game theory model using systematic review methodology. The theoretical framework for designing software called Hypertension Management System (HMS) is proposed using underlying principles of game theory by considering patients and doctors as players. The system is installed in the smartphones of players and its functioning follows the hierarchy of Big Data mining and extraction. The theoretical framework of HMS starts from data sensing through physical sensors, proceeds along layers for data processing and reduction, and finally arrives at the decision-making step to assist doctors in the treatment of disease. This novel system will reduce the mortality due to chronic diseases like hypertension by enabling game patients and doctors to deal with its symptoms in a timely manner according to feedback from previous data.*

Keywords: Big Data, Bluehost cloud, Game Theory, Nash Equilibrium, Decision support interface, XML, Hypertension Management System (HMS).

Introduction

The medical consultation is best described as the interaction between patients and doctors with interests either shared or conflicting. With the advancement in the healthcare facilities and awareness of patients, the interests of both parties are becoming quite sophisticated. The conflict of interest arises because doctors would recommend some treatment that patients cannot pursue due to cost or some other reasons (Caplan, 2011). Even wealthy patients sometimes feel the treatment is not up to the desired standard (Hozo, 2015). The efforts of doctors, on the other hand, are always oriented towards the welfare of the patients in different ways.

The conflict of interest associated with the social interaction between doctors and patients can be described through Game Theory. The doctors and patients involved in the interaction are considered players. The players make optimal choices according to their own sense of game. The revolutionary game theory concepts could be utilised in healthcare management for the treatment of chronic diseases like hypertension.

Hypertension is one of the chronic diseases in which the blood pressure in the arteries increases (Alessa, 2018). It is also a precursor of many other chronic diseases like renal failure, heart attack, and stroke (Chobanian, 2003). This research study shall undertake the challenge to design a modern hypertension management system based on game theory. The

proposed system uses a mobile app that contains features for monitoring and controlling hypertension by considering the conflicting interests of patients and doctors.

Literature review

The research field of clinical health assessment, patients' monitoring, and health management have been quite flourishing since the last decade mainly due to advances in technology. The health sector is being digitised for management of various diseases like hypertension, elevated blood pressure, diabetes, through remote wearable sensors and mobile apps (Alessa, 2018; Kangand, 2015; Liang, 2018). Many research results are reported for assessing the feasibility of digital technology in the management of chronic diseases through interactive coordination between patients and doctors. Most of the results assert that IT based solutions in any form are quite useful in lowering blood pressure and controlling hypertension. However, care must be taken while using technological solutions as they could contain some bias or misleading problems. Through self-care and life style changes, chronic diseases can be easily managed (Drevenhorn, 2018).

The healthcare sector is moving towards more innovation for improving the facilities for patients. Multiple features have been explored that benefit the broader population of patients instead of focusing on just individual clinical cases (Kiss, 2018). The concept of the game theory is essential in this regard that multiple constraints are being optimised among players (doctors and patients). The treatment methods that provide optimal choice for patients and doctors are explored using a complex game theory perspective (Hozo, 2015; Tarrant, 2004). The famous case studies of Prisoners' Dilemma, Assurance game and Centipede game are analogous to the interactive decision-making regime in the modern healthcare sector (Hozo, 2015). Moreover, the importance of monitoring-based clinical health assessment and decision making is also emphasised (Cappello, 2017; Lynch, 2016).

The game theory model solves many problems in the healthcare sector including the dilemma of choice between patients and doctors and even health care providers themselves (Bettinger, 2016). The healthcare research model based on game theory still has many unidentified areas to explore. This aspect provides the motivation for the current study. In this research paper, we are going to propose an innovative health monitoring app for hypertension management using game theory model. The app should assist in life style modifications for lowering hypertension through various means.

Decision support interface & system architecture

In order to utilise the game theory model and digital technology, a revolutionary app is proposed for hypertension management. The design of the mobile app follows the layered architectural scheme (figure 2.) with features included from information gathering through primary sensors to decision making from a database containing patients' records.

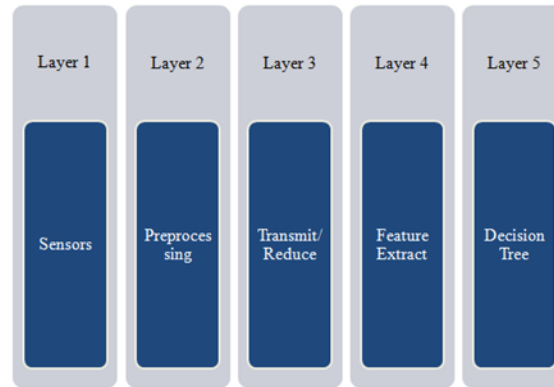


Figure 2. Proposed Layered Architectural Model for HMS

Hypertension Management Software (HMS) uses clinical procedures, guidelines, treatment methods, and other healthcare methods to optimise hypertension management. The interactive decision-making regime is based on game theory model. The software is designed through a series of following stages that communicate and coordinate with each other to complete the model using game theory perspective:

- **Data Acquisition from Sensors:** The hypertension is measured through wearable sensors mounted on the patients' body. The sensors communicate with the HMS app installed on the mobiles of players under consideration (doctors and patients).
- **Data Preprocessing and Transformation:** The data is gathered in the app and transformed into a suitable documentation format like XML, RTF, Doc, PDF, or some other format suitable for reading in electronic gadgets.
- **Data Transmission and Reduction:** The data obtained from the app is transmitted to the central cloud-based servers for storage after reduction and compression.
- **Feature/Knowledge Extraction:** The case studies of patients are analysed in the light of data aggregated on cloud servers through feature extraction. The algorithms and methods pertaining to game theory models are applied.
- **Decision Tree and random forest** utilise the optimisation strategies of game theory to provide final hypertension management and control methods layered as below:

Data acquisition from sensors

The conventional blood pressure measurement through obtrusive inflatable cuffs doesn't provide a complete picture of hypertension around the clock. The trends of BP in ambulatory and sleep setting provide insight into the diagnosis of chronic diseases (Radha, 2018). To monitor blood pressure regularly and provide representative trends, the wearable sensor devices like Photoplethysmography (PPG) are innovated (Radha, 2018). The development in non-invasive blood pressure measurement in recent times has led to tremendous improvement in healthcare with respect to monitoring of chronic diseases and treatment (Arakawa, 2018; Lin, 2015).

The HMS utilises the wearable non-invasive blood pressure measurement device for sensing (Figure 1.) and relaying hypertension information in suitable units to the HMS app running on the mobile phones of game theory players (doctors and patients). These sensors regularly monitor the blood pressure trends during various physical states of the patient. The

people who are vulnerable to developing hypertension due to family history, diet, elevated blood pressure or lack of exercise are recommended to use this device to diagnose the ailment at early stages.

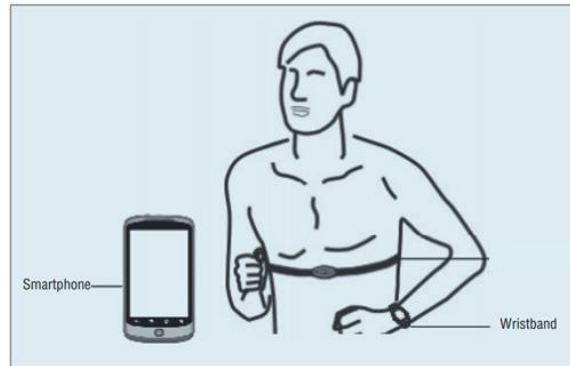


Figure 1: Wearable Sensor Communicating with App (Lin, 2015)

The wearable non-invasive sensors are powered by miniature batteries that run at least a day and must be charged regularly to ensure proper monitoring. The sensors are provided with charging devices for restoring the battery status to full in a short time. The wearable electronic circuitry also provides the communication module for relaying hypertension information to the mobile app through WiFi. The device is initially configured to communicate with the mobile app of players and then it reconfigures itself in the future. The trends and data about blood pressure are regularly transmitted for further processing in the app.

The data acquisition from sensors considers the unobtrusive nature of the wearable electronics a great deal to ensure the comfort of the patients. The circuitry doesn't affect any daily routine activities of the patient. They keep on moving and get engaged in various tasks and their health is being monitored in the background through sensors and remote surveillance system managed through HMS. The unconstrained nature of wearable sensors is one of the most significant innovations in the healthcare industry to enhance the overall monitoring of health parameters.

The configuration of the hypertension measurement sensors is performed in our proposed system to record any abnormal changes in the blood pressure and immediately alarm the healthcare personnel through a particular alarm signal. The absolute high value of the blood pressure and sudden high rate of change must be immediately notified to the doctor to ensure the good status of the patient. The data about normal blood pressure readings and day-wise trends are recorded through the app to maintain a complete health profile of the patient and utilise game theory model for interactive decision making.

The game theory perspective is included in the interaction between doctors and patients regarding the monitoring of blood pressure and prevalence of hypertension. The doctors recommend measures to control blood pressure through proper consultation and taking patients in confidence. The stakes of both parties are consolidated and optimised to assume a win-win situation.

Data pre-processing and transformation

Once the data is gathered from wearable sensors in the form of blood pressure readings, they are pre-processed in the Android app running on smartphones of game players in this model. The requirement of pre-processing occurs due to the raw form of the data obtained from sensors. The data must be managed and converted into a suitable document format for further processing and analysis in the next layers. Moreover, the wearable sensors transmit data regularly, so it amounts to a huge volume of space. Thus, it must be made concise and compressed to support analysis.

The data pre-processing is performed to convert data into XML (Extensible Markup Language) format. It contains friendly features for encoding by machines and also friendly for analysis by humans (Spencer, 1999). XML has become the standard technology for communication and coordination among various devices. It assists in standardisation, integration of data, and representation of complex data structures in a simpler format (Vandersluis, 2004). Moreover, the XML format is becoming an increasingly common format for local file processing (Salminen, 2012).

Conversion of raw data to XML format is also challenging due to the coding of complex algorithm to integrate and standardise data (Salminen, 2012). However, the complexity of conversion into XML is traded off with the benefits it provides. So, this format assists a lot in overall system architecture in Big Data regime. The algorithm of conversion of data into XML should be implemented in the software Android app and it can be output to the next layer for further analysis and processing.

The cost associated with this layer is not much because of indigenous operation of the process after initial coding. However, the programmers must update the algorithm as the technology of XML continues to improve and grow. Moreover, the pre-processing must be tested regularly for proper operation.

Data transmission and reduction

The next milestone in the system architecture is data transmission and reduction. This phase lies at the heart of the system because it provides centralised access to data to game players. The doctors and patients could consult records, exchange proposals during online interaction through the app, and analyse trends using data available on central servers.

For centralised data access, cloud storage and computational services are used. The cloud model offers benefits of robustness against random errors, distributed algorithm, easy access to data from anywhere, computational services, and reliable (Puttini, 2013). The choice of cloud service is essential that would offer all these benefits in an effective manner. BlueHost is regarded as one of the best players in this regard (IRMA, 2018). The superior cloud services of BlueHost could be utilised in patients' record keeping for data analysis in our proposed Big Data model.

The data obtained from the previous layer in the XML format is transmitted to the central servers managed by BlueHost on the internet. The data is transmitted from the Android App through WiFi. The storage capacity on the cloud server is sufficient to store records of thousands of patients. The data must be appropriately managed before storage. So it is compressed in a suitable file storage format for easy collection, sorting, storage, and retrieval on request of players.

The data transmission from the app to central servers is performed through encryption considering the sensitivity of the information and protocol. The data is backed up on physical storage devices also in case of a rare scenario of cloud server unavailable. The physical storage devices could be 1Terabyte multiple hard disks kept in the concerned hospital for record.

Once the data is stored at central servers, it is reduced and compressed. The data reduction carries significant benefits in statistical analysis and forensic investigation in Big Data regime in medicine and the health sector (Quick, 2018). The data reduction compresses and organises data in a proper way for data analysis and mining through the proposed game theory model. Although, data reduction and analysis are employed mostly in physical sciences (Bevington, 2003), yet their effectiveness in the medical field is beyond any doubt.

The basis of data reduction is kept as the type and nature of the trends associated with blood pressure. For example, the data containing high blood pressure trends are gathered and simplified in the form of graphs, and statistical analysis results like averages, regression equations, and so on. Similarly, the low trends of blood pressure could be organised and simplified using statistical methods.

The application of data reduction ensures that Nash equilibrium is avoided to the maximum extent (Spaniel, 2011). The game theory model asserts that doctors and patients are aware of the equilibrium strategy to cope with the disease through particular treatment methods. The choice of doctors and patients should coincide instead of one of the parties staying adamant on its decision. For example, the patients should have their suggestions in response to treatment, but the doctors' decision must be optimal considering patients are willing to adjust accordingly. The contradiction between players shouldn't lead to Nash equilibrium in which no party can benefit by changing strategies while the other party stays unchanged and inflexible.

Feature/knowledge extraction

Feature extraction is a renowned machine learning method employed in the field of pattern recognition (Guyon I. G., 2008). The algorithm aims to extract and acquire useful features or items from the huge data stored on servers. It is also a form of data reduction or compression in which redundancies and duplications are avoided and data is consolidated in a specific manner. The raw data stored on servers through defined classification could be systematised effectively using specific features or patterns (Guyon I. E., 2006).

The machine learning algorithm for feature extraction is developed through well-defined methods. These procedures could employ features related to symptoms and indications of hypertension to extract useful features like time duration which a particular blood pressure trend prevails, average blood pressure in a particular month, and so on.

Due to the diverse nature of data structures related to the medical field, pattern recognition and feature extraction is a challenging task (Gorodetsky, 2010). It involves identification, sorting, and analysing important features of a massive amount of data stored in central servers. Due to the limited resources of cloud computing services and other facilities in the model, it is essential to process data at various stages.

The Big Data regime till cloud computing in the previous layer has already compressed data to a great extent that makes feature extraction computationally efficient. The information about different partners is acquired through software embedded in the app installed on smartphones of patients and doctors. The process of feature extraction performs

statistical analysis on data to identify patterns like correlation, statistical regression, combinational logic, and so on.

Decision tree and random forest for displaying the advice in bad values ***Case for Individual Blood Pressure***

As the HMS architecture evolves from layer to layer, the features and patterns associated with them are becoming concise and accurate. The last layer in this architecture is the cornerstone of the overall decision-making process. The decision tree is the special algorithm in the data mining context in which the items and events move along the branches of the tree due to various conditions and constraints (Prajwala, 2015). The hierarchical model of decision tree sorts the options based on the given conditions and provides the best possible estimate of the solution to the problem concerned.

The decision tree could be considered as the machine learning algorithm that takes the role of the doctor in software. It assesses the conditions based on the reports of the patients and narrows down the suggested conditions. The set of conditions are evaluated against the patterns obtained from the feature extraction step.

The decision tree is implemented in the software as all other layers in this architecture. The notion of the decision tree is visualised against a set of constraints which are narrowed down to specific conditions in the algorithm. The programming of this algorithm is implemented in software in the Android app.

The field of medical diagnosis is moving towards automation and digital technology using Big Data to assist in the decision-making process using data structures like a decision tree. Our proposed model could run decision tree analysis against the case studies of patients under examination. The decision tree analysis will aid and complement the role of the doctor. The feedback and historical evidence obtained from data analysis through decisions trees will assist the doctor in the treatment of disease.

The data structure of decision trees presents a compelling case in terms of standardisation and simplicity of decision making through categorisation. The basis of setting tree nodes and tree depth is very important. The solution orientation must be unique to arrive at a concrete decision with respect to a given case study. The data obtained from feature extraction is processed according to the constraints of the case study and decision is evaluated in terms of diagnosis and possible treatment methods.

The importance of the decision tree in the realm of HMS is critical considering the complexity and chronic nature of the disease. The involvement of the decision-making framework to assist doctors in decision making makes life easier for patients and doctors. The proposed HMS treatment model is based on the mobile app through the application of game theory. The layer of decision tree also assists in game theory implementation in a practical scenario. The conflict of decision between patient and doctor could be resolved through the decision tree verdict. It will analyse the situation and remove the biases on either side to suggest the optimal solution of the problem.

Some situation leads to multiple decision trees; then we will have a data structure of the random forest. The notion of forest indicates that it contains some trees corresponding to different situations and constraints. The structure of the random forest has many times more computational and structural complexity as compared to a single decision tree. However, with the help of software app of HMS, the algorithm of the random forest will be evaluated and the resulting decision will be obtained.

Methodologies used

The method used in this research study is a systematic review of literature related to Big Data, the involvement of technology in medicine, gaming theory, hypertension diagnosis and treatment. We included the studies based on the inclusion criteria of recent studies up to a maximum of 10 years old and containing content on the topics mentioned above. The research studies are acquired from reputed journals and conferences through the Google Scholar search engine.

The software model of the system is extracted from the recommendations and ideas presented in the literature. The layers of the architecture are standard and used in various software models of Big Data analysis and feature extraction. The basis of the proposed architecture is taken from clinical decision-making models (El-Sappagh, 2014; Velickovski, 2014; Banning, 2008; Coulter, 1997; Standing, 2008). The hierarchy of the model allows some kind of decision making at every layer. As the algorithm moves forward between different stages, the data is processed and simplified according to software algorithms. The proposed design of the Android app follows the guidelines and principles of digital communication with respect to encryption and security (Wafar, 2011) due to sensitive information of patients' diseases (Bryan, 2009).

The implication for personal monitoring mHealth App and reducing abandon of a personal health program

The application of HMS app will be numerous and will have a strong implication on the health sector for controlling the prevalence of chronic diseases like hypertension. The personal health monitoring app will assist patients and doctors in monitoring trends of blood pressure. Any abnormal changes could be diagnosed very early and treatment measures shall be adopted depending on the decision obtained from HMS framework.

The positive impact of health monitoring app in the form of HMS will reduce the abandonment of programs and precautions related to health management at an individual and collective level. The awareness among patients and doctors will grow regarding hypertension and they will take suitable measures to cope with such diseases (Guo, 2012; Hajjar, 2003).

Due to the high proliferation of technology in the modern era, the game theory model could be easily implemented in the health sector with the help of interactive communication and coordination. The health monitoring app HMS allows patients and doctors to share symptoms and recommendations. Doctors suggest treatment measures that avoid Nash equilibrium (the measures that require an assumption of particular action from other players who will stay in equilibrium) (Landau, 2007; Complex Systems Modelling Group, 2010; Athanasiou, 2011).

The positive implication of remote health monitoring system for hypertension will inevitably reduce the prevalence of this disease among people. Moreover, early diagnosis and treatment will reduce the mortality rate. By monitoring trends and behaviour of blood pressure, the patients could take preventive measures and avoid severe outcomes.

Future works

The field of IT and digital technology in the realm of Big Data framework is rapidly evolving in the health sector. The future research directions could be related to exploring innovative software approach to deal with other chronic diseases like heart attacks, diabetes, and strokes. The existing literature provides a framework for developing the architecture for remote assistance of patients. Future work can improve the remote monitoring of patients by proposing methods for communication and coordination. The research methodology proposed in this paper moves along a particular hierarchical framework for software model. The hierarchy of steps could be modified to include more layers that strengthen the privacy and security aspects of the approach. This system is quite sensitive due to its implications in the health industry mainly related to the treatment of chronic diseases. Another suggestion for future research work is the exploration of game theory models that assist in remote health assistance and clinical decision making. This research direction is innovative and useful because patients are becoming aware of their diseases a great deal and their interaction with doctors generally follows the game theory model.

Conclusions

This paper proposed a novel hypertension management system framework in the form of an Android app for monitoring and treating this disease. The proposed model of the app is based on game theory and follows the architectural hierarchy of generalised software development. The methodology of the systematic review was adopted to include results in the domain of remote health assistance and clinical decision making with the help of game theory model.

The HMS framework started with a measurement of the physical parameter of blood pressure with the help of a wearable sensor that transmits information to the Android app installed on mobiles of patients and doctors. The information is converted to XML for ease of storage and processing. The data is transmitted to the central servers for centralised access to all data through the internet. The data is compressed and reduced to extract features and patterns in the next layer. The features are extracted based on particular symptoms and directions obtained from the given case study. Finally, the framework aids doctors in decision making by providing hints about diagnosis and treatment using decision tree and random forest data structures. The overall model follows the layered hierarchy in which each layer processes Big Data and refines the processing for the next layer.

The proposed model takes care of terminologies and concepts acquired from game theory model with patients and doctors considered the part of the game as players. The constraints of patients are considered for avoiding Nash equilibrium. This model could assist further development of clinical decision making in the health sector.

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