Building, training and validation an artificial intelligence-assisted Early Warning System for COVID-19 pandemic management

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Abstract: Over time, even in the modern world, epidemics and pandemics have caused millions of deaths. Moreover, Europe and, implicitly Romania, are facing an aging population, which will be a crucial challenge in the fight against viruses for the coming years. Therefore, in the case of pandemics, as is the case Covid-19 pandemic, launching an artificial intelligence-assisted program, which could help pre-sort patients arriving in hospitals, has become crucial. This pilot study is a first phase of the UEFISCDI Project, T1 - Approaches to public health management in the context of the COVID-19 pandemic, in which "Carol I" National University is involved. The pilot study has the purpose and expected outcome to develop and implement an artificial intelligence-assisted early warning system able to make warnings and projections on the diagnostic and treatment capacity of COVID-19 cases in hospitals from different areas.

Keywords: early warning, artificial intelligence, machine learning, diagnostic capacity, pandemics, COVID-19.

Construcția, instruirea și validarea unui sistem de avertizare timpurie asistat de inteligență artificială pentru gestionarea pandemiei COVID-19

Rezumat: De-a lungul timpului, chiar și în lumea modernă, epidemiile și pandemiile au provocat milioane de decese. Mai mult, Europa și, implicit România, se confruntă cu o populație îmbătrânită, ceea ce va reprezenta o provocare crucială în lupta împotriva virușilor în următorii ani. Prin urmare, în cazul pandemiilor, așa cum este cazul pandemiei COVID-19, lansarea unui program asistat de inteligență artificială, care ar putea ajuta pre-sortarea pacienților care sosesc în spitale, a devenit crucială. Acest studiu pilot este o primă fază a Proiectului UEFISCDI, T1 - Abordări ale managementului sănătății publice în contextul pandemiei COVID-19, în care este implicată Universitatea Națională „Carol I”. Studiul pilot are scopul și rezultatul scontat de a dezvolta și implementa un sistem de avertizare timpurie asistat de inteligență artificială capabil să facă avertismente și proiecții cu privire la capacitatea de diagnostic și tratament a cazurilor de COVID-19 în spitale din diferite zone.

Cuvinte cheie: avertizare timpurie, inteligență artificială, învățare automată, capacitate de diagnostic, pandemii, COVID-19.

1. Introduction and preliminary concepts

Under the conditions of the COVID-19 pandemic and its multiple consequences (ensuring the health of the population, economic losses, geostrategic effects etc.) the design and implementation of an "artificial intelligence-assisted Early Warning System for COVID-19 Pandemic management" should be a national priority for the healthcare system and for any other organizations/systems with which it interacts. At the international level there is a large effort to optimize the flow of data and information for the management of health systems, as studies (Jason et al., 2020) show that medical and economic efficiency is strongly influenced by the level of development and complexity of implementing an integrated epidemiological monitoring and modeling system.

The analysis of recent literature shows various approaches and solutions, adopted by public institutions in Europe, the United States, China, Russia and Japan etc., but characterized by heterogeneous approaches: deep-learning (Gozes et al., 2020), virtualization and 3D, AI techniques

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and the use of smart phones, which do not fully appeal to standards and methodologies recognized in the field and involve the use of various systems, inhomogeneous, at various times of life cycles. This leads to data redundancy and reduced possibilities for functional extensibility and integrality.

The solution proposed in this study is addressed to all public and private institutions involved in combating the COVID-19 pandemic (Ministry of Health, Ministry of National Defense, Public Health Directorates, hospitals, pharmacies, patients), using methods and standards recognized in the field (SOA architecture, compliance with the GDPR standard).

1.1. The concept of early warning and the use of Early Warning Systems (EWS) in different fields of activity

Generally speaking, predictive techniques are a combination of objective and subjective measures that aim to provide useful recommendations in further developments, in order to warn and avoid errors (Marinescu et al., 2019).

The general idea of early warning is a broad concept. It can be applied in almost any field where it is important to get clues as soon as possible about problems, some of which are emerging (Popescu, 2019). Based on the authors' expertise, working for various international organizations (UN and NATO agencies), two sound models of using the concept of early warning were experimented, hence the idea to expand this concept in the field of pandemic management assisted by artificial intelligence.

In order to highlight the importance of early warning systems for different organizations, we will further present the main types of hazards and the warning systems associated with them. The types of hazards analyzed are: *severe weather*, *landslides/floods, drought, fires, earthquakes, volcanic eruptions*, *tsunami*, and *epidemics.*

Regarding *severe weather*, a field leader is the World Meteorological Organization (WMO), that provides information for 189 countries/territories on hydro-meteorological hazards. WMO observes, monitors, anticipates and warns specialized regional centers on tropical cyclones, heavy rain/snow, thunderstorms, gale and fog. More data can be accessed on https://severeweather.wmo.int/.

Another warning system that can fit into the context presented is the Atlas project. This is a warning system, developed by the University of Hawaii, that monitors the movement of asteroids that can affect Earth. For details about near-Earth asteroids, potentially hazardous asteroids, comets and supernovae the site is http://fallingstar.com/home.php.

IFRC in partnership with International Research Institute for Climate and Society have developed an early warning system that presents on the Internet data about atmospheric circulation, heat waves, atmospheric temperature, drought, seasonal and sub seasonal forecasts, heat waves. The site can be accessed at http://iridl.ldeo.columbia.edu/maproom/ Global/index.html.

On the second hazards analyzed *landslides floods*, our attention is on Global Flood Alert System (GFAS)II. This early warning system was released in June 2017 by IDI-Japan and shows a global risk map of possible rain-related disasters about one hour behind time, according to the data on the site http://www.internationalfloodnetwork.org/gfas.html.

The next hazard we focused in our analysis is *drought*. One of the best early warning tools is the one provided by Global Drought Information System (http://www.drought.gov/gdm/) were we can access interactive map on current conditions that contains: Gridded Population of the World, Vegetation Health Index (VHI), Evaporative Stress Index (ESI) and GPCC Drought Index. This instrument can provide customized data on continents, regions or cities and can thus be a useful tool in crisis management. Connecting the danger of drought with hunger, The Food and Agriculture Organization (FAO) developed an early warning tool named The Global Information and Early Warning System on Food and Agriculture (GIEWS) that can be accessed on www.fao.org/giews/english/index.html and can provide early warnings of impending food crises at country or regional level.

On next hazard, we concentrated the analysis on *fires*, *earthquakes*, *volcanic eruptions and tsunami*. For all these hazards there are different and complex early warning systems, such as: Global Fire Early Warning System, European Forest Fire Information System, USGS Earthquake Hazards Program of the U.S. Geological Survey (USGS) Geofon, UNESCO Intergovernmental Oceanographic Commission Tsunami Programme US Tsunami Warning System. All these systems could be explored on the sites in references.

Last but not least, it is very important to stress in this study that World Health Organization has developed over the time a Health Emergency Dashboard, linked to COVID-19 pandemic, which serves an early warning system "to share information about public health events and emergencies. The data on the dashboard is refreshed every fifteen (15) minutes and data is accurate as at time of refreshing". https://extranet.who.int/publicemergency.

The objectives set for building, training and validation of an *artificial intelligence-assisted hybrid early warning system* for COVID-19 pandemic management are:

- helping hospital managers make better-informed decisions in the form of preventive and/or corrective actions, and to provide a better basis for monitoring the performance of the medical act;
- contributing to the development of proactive strategies, and consequently to back-up scenarios when hospitals face pandemics (COVID-19);
- quantifying the different scenarios and explaining them quantitatively and qualitatively.

1.2. Artificial Intelligence (AI)

Although artificial intelligence seemed no long ago to be from the field of science fiction, it is actually a notion that has emerged since antiquity. Greek mythology, for example, speaks of the mechanical creations of the god Hephaestus. In Jewish folklore, golems are animated anthropomorphic beings, created from clay. Even Dr. Frankenstein's monster, the main character in Mary Shelley's story, refers to the idea of man-made artificial intelligence.

Now, more than ever, it is present in our lives, reshaping the world we live in and manifesting itself in various forms:

- chat bots that use AI to understand customers' problems faster and to provide more efficient answers;
- referral engines, which make automatic recommendations for TV shows, depending on the viewing habits of users;
- smart assistants that analyze essential information from large text datasets to improve programming.

1.3. How an AI system learns

In addition to programmed Artificial Intelligence, there are currently three other ways in which an AI system can learn new things.

Machine Learning is an important part of Artificial Intelligence. It is a type of research through which computers receive a huge amount of data that they analyze, from which they learn and on the basis of which they (re) act, without the need for specific programming (Kersting, 2018). An example of this is represented by virtual assistants who can understand voice commands. *Deep Learning* is a much more in-depth method of machine learning, through which computers learn to do things in a way very similar to humans learn from experience. Deep learning is the key technology behind autonomous cars and what allows them to identify a STOP sign or differentiate between a pedestrian or a lighting pole. In short, deep learning allows a computer to learn directly from sound, text and image.

Neural networks are the core of Artificial Intelligence and are essential for machine learning. These are interconnected networks of algorithms, inspired by biological neural networks, existing in the human brain. These networks exchange data and can be programmed to perform certain tasks in a complex way that attempts to mimic human thinking.

2. Analysis of medical fields in which machine learning has provided promising results

Although the machine learning speed evolution is fast in most areas and facilitates people's work processes, major invasions are expected in the medical field. In this section, multiple applications of A.I. - machine learning in the medical field in the last 10 years are analyzed. Thus, the following medical fields have been identified in which machine learning has provided promising results:

2.1. Clinical trials

Machine learning models are increasingly used in the identification of possible diagnoses. For example, in a study, published on European Heart Journal, it was established that machine learning algorithms can be used to determine proxies for the National Institutes of Health Stroke Scale (NIHSS) score and the assessment of stroke severity related outcomes (Kogan et al., 2018). This study was a step forward in the field because it used only administrative claims data to feed machine learning algorithms.

In Sleep, journal for sleep and circadian science, an interesting topic was published this year related to possible diagnose in obstructive sleep apnea (OSA). A machine learning method known as Supersparse Linear Integer Models (SLIM) obtained good results of diagnosis by translating the results of a laboratory-based population in a community-based population. The test characteristics for the Electronic Health Record (HER) were managed by SLIM machine learning tool (Patel et al., 2020) and automated screening results can be useful for patients and doctors.

2.2. Identification of possible diagnoses

Artificial intelligence has already made its way through hospitals around the world. Those who control it have no cause for concern because it is developed to ease the doctors' mind, to help them and not to replace them.

The medical futurist, Bertalan Meskó, called Artificial Intelligence "The Stethoscope of the 21st Century" (Meskó, 2017), and the assessment made by him seems to be even more accurate than expected. While various techniques and tests provide all information needed to diagnose and treat patients, doctors are already overwhelmed with clinical and administrative responsibilities, and sorting out a massive amount of available information is a daunting, if not impossible, task at times. In this case, the 21st century stethoscope could make a difference.

In medicine, it seems that Artificial Intelligence gradually exceeds the threshold of administrative work. From powerful diagnostic algorithms, to well-regulated surgical robots, the technology makes its presence known in different medical disciplines. Clearly, Artificial Intelligence has a well-established place in medicine, the unknown variable being its value.

Although we are still in the early stages of its development, Artificial Intelligence is already able, like doctors, to diagnose patients. Researchers at John Radcliffe Hospital in Oxford have developed a more accurate AI diagnosis system than doctors in 80% of heart disease cases (Gillepsie, 2018).

At Harvard University, researchers have created a "smart" microscope that can detect potentially deadly bloodstream infections. The AI-assisted instrument was trained on a series of

100,000 images obtained from 25,000 dye-treated slides to make bacteria more visible (Caughill, 2017).

The AI system can already sort those bacteria with an accuracy rate of 95%. According to a study by Showa University in Yokohama, Japan, a new computer-assisted endoscopic system can reveal signs of colon cancer with a sensitivity of 95%, a specificity of 79% and an accuracy of 86% (Mori et al., 2018).

In some cases, according to researchers, AI can outperform doctors in urgent diagnoses, which could be of great use to physicians, especially in terms of how long they have to make a diagnosis or make a decision regarding surgery. Therefore, it could make their job easier, one way or another. According to a study published in December 2017 in JAMA, deep learning algorithms were able to better diagnose metastatic breast cancer than human radiologists when they were in a time crisis (Bejnordi et al., 2017). While human radiologists do well when they have unlimited time to examine cases, a quick diagnosis could make the difference between life and death.

2.3. Personalized treatment

Another medical domain to be improved with machine learning models is personalized treatment. Smoking cessation treatment is one of the most attractive topics for specialists, smokers and society in general. Can machine learning models give a hand on this issue? In Nicotine & Tobacco Research, a team of experts proved that a machine-learning approach could be a solution to predict smoking cessation treatment outcomes (Coughlin et al., 2018). The machine learning model offers a decision point to help doctors take the proper treatment, specific to each patient.

In 1989, Chris Watkins in his PhD thesis, introduced the notion of Q-learning (Watkins, 1989). This machine learning model was used by a team of experts to develop personalized adaptive treatment strategies (ATSs) on acute graft-versus-host disease (Krakow et al., 2017).

Autism is one of the most common disorders of childhood that affect a significant number of children. The social abilities of the patients with autism spectrum disorder are some of the most affected abilities. A team of specialists demonstrated that fusion of magnetic resonance imaging (MRI) data and machine learning could refine diagnostic accuracy, especially at the local neurocircuit level (Dekhil et al. 2019). These results can improve the personalized treatment that doctors can offer to patients identified with autism.

2.4. Radiology and radiotherapy

MRI or CT imaging medical data provides a visual representation of the human body, which becomes the main resource for doctors who want to identify the root cause of a patient's discomfort. The more scans they see, the more accurate they are at detecting anomalies. The more diverse the patients, the wider the spectrum of diseases they can recognize. Therefore, volume plays a key role in accurately diagnosing patients. AI covers the gap between the heterogeneous distribution of information and the correct diagnosis. With data from hundreds of thousands of patients, annotated by the best specialists through high computational power, a neural network-based algorithm can learn patterns based on the common knowledge and experience of several medical professionals, surpassing people in speed and accuracy. Due to the increased attention to detail, a single standard neural network architecture may not be sufficient. Depending on the area of interest of the researchers, the approaches can vary from segmentation via U-nets or V-nets, to feature cascades, but also to feature extraction and classifications from the CNN - RNN spectrum. One cannot predict which algorithm will work best - we need to explore more options.

Take the example of XVision, a medical platform that analyzes lung radiographs using artificial intelligence, which began to be used to identify patients with lung lesions associated with COVID-19, the solution becoming part of mobile laboratories for coronavirus detection located outside the Institute of Pneumophthisiology "Marius Nasta" from Bucharest (see Figure 1). "This new way of sorting medical cases will reduce the risk of contamination of other patients already hospitalized, but also of medical staff. In addition, this MedTech solution supports the medical team in managing the extremely heavy workload during this period", report the XVision representatives (Zamfir, 2020).

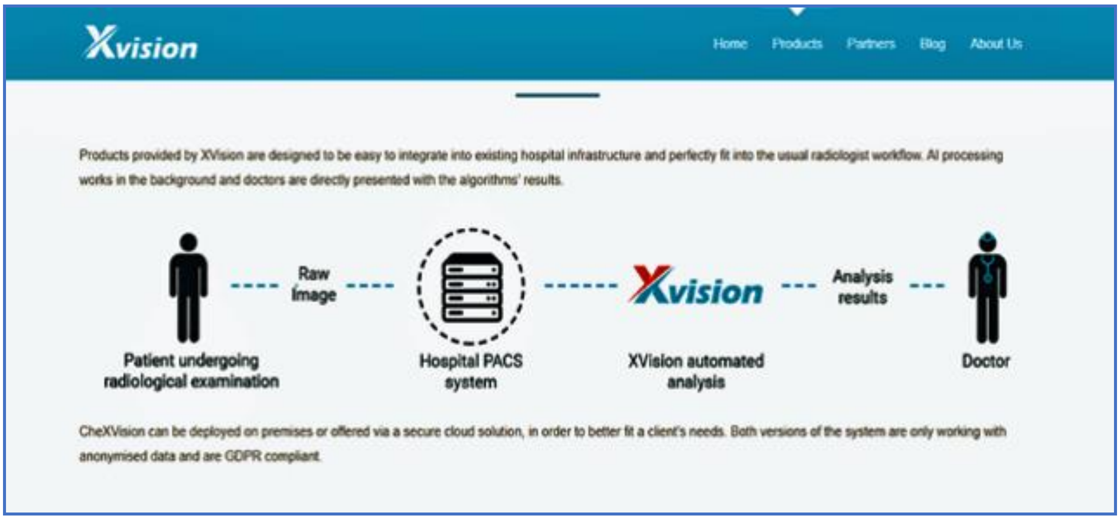

Figure 1. XVision cycle. Source: XVision.app

The triage system is based on an evaluation score developed by XVision's team of radiologists, relative to the scores and standards currently used globally. It describes how similar the algorithm considers the radiological patterns in the patient's radiography to those found in COVID-19 cases. As part of the triage, after the x-ray is performed in the mobile laboratory, the XVision application provides a very fast result that is analyzed by doctors, along with the initial x-ray. Depending on this, a decision is made regarding the respective medical case. XVision detects signs of pneumonia, even incipient, and assigns a degree of resemblance to the radiological pattern of pneumonia with that specific to COVID-19 (see Figure 2).

Figure 2. XVision detects signs of pneumonia. Source: XVision.app

2.5. Smart devices for medical records

Somehow, in parallel with research in genetics, humanity inexorably evolves in terms of electronic and digital technologies (Popescu & Scarlat, 2017). Portable technology devices, such as FitBit, easily measure medical data in real time. Digestible sensors, biometric tattoos and RFID readers can transmit medical information and serve as patient identification devices. New Deal Design Company, who designed the bearer line FitBit devices, is now working on a new project called under-skin. It is a smart digital tattoo implanted subcutaneously in hand and will interact with any electronic device touched by the person (Popescu et al., 2018).

These sensors can measure all important parameters and vital signs of patients, from temperature to blood biomarkers, transmitting real-time data in the cloud and alerting healthcare professionals when a patient suffers a stroke. The first digital pill appeared (Andalo, 2017), a pill that contains a sensor, with which doctors can find out what is happening in patients' bodies - whether they follow the recommended medication or not. Experts from the above mentioned journal estimate that patients who do not take their drugs cost nearly $ 100 billion a year because their health is deteriorating and they need additional treatment. Thus, through these applications the behavior of patients is changed and medical costs are reduced. New technologies help patients sleep better at night, maintain optimal blood pressure and a healthy heart, measure patients body temperature, track patients body weight and promise to relieve stress. The fact that patients can monitor their body alone makes them more responsible for their own health. However, a wearable device can only display data and patients do not know what it should change. Finding a medical solution and adopting a healthy lifestyle is up to patients, but interpreting the data requires the guidance of a doctor.

3. Brief description of the pilot platform for the artificial intelligence-assisted Early Warning System for COVID-19 pandemic management

The method used in this pilot platform is an integrated open-source portal for public health management in the case of the COVID-19 pandemic. The role of the portal component is to display the web interface which will be standardized, simple and intuitive, according to the recommendations of the World Wide Web Consortium, hereinafter referred to as W3C or HTML5. The portal will be entirely a web type that will allow the integration with all actors involved.

Today, machine learning methods are becoming increasingly sophisticated, being integrated, for example, into a number of complex medical applications, such as diagnosing pandemics/epidemics (Jiang et al., 2018). Machine learning uses a variety of algorithms that take data and predict certain results. Algorithms differ depending on the data received: if the data is labeled, we will have supervised learning algorithms, and otherwise, unsupervised learning. (Paraschiv & Ovreiu, 2020).

The pilot platform as a first step of the UEFISCDI Project, T1 - Approaches to public health management in the context of the COVID-19 pandemic, is a web application, based on an HTTP protocol, using a C# programming language, an SQL server and a visual studio (see Figure 1). The role of the C# programming language in the pilot platform for the Artificial Intelligence-Assisted Early Warning System (EWS) for COVID-19 pandemic management is to connect the database servers from COVID-19 epidemic hospitals to the interface of ordinary users who have access to the application and introduce their symptoms in the questionnaire that starts the application.

The SQL servers in the pilot platform underlying the Artificial Intelligence Assisted Early Warning System for COVID-19 management facilitate the management, storage and correlation of data provided by hospitals intended for COVID-19.

The self-diagnosis subsystem for potential patients Cold/Flu/COVID-19 or other epidemics consists of 3 layers and has inputs (expertise and knowledge acquisition) from hospitals' databases (see Figure 3):

- Presentation layer (multimedia interface).
- Domain layer (inference engine).
- Data access layer (SQL server).

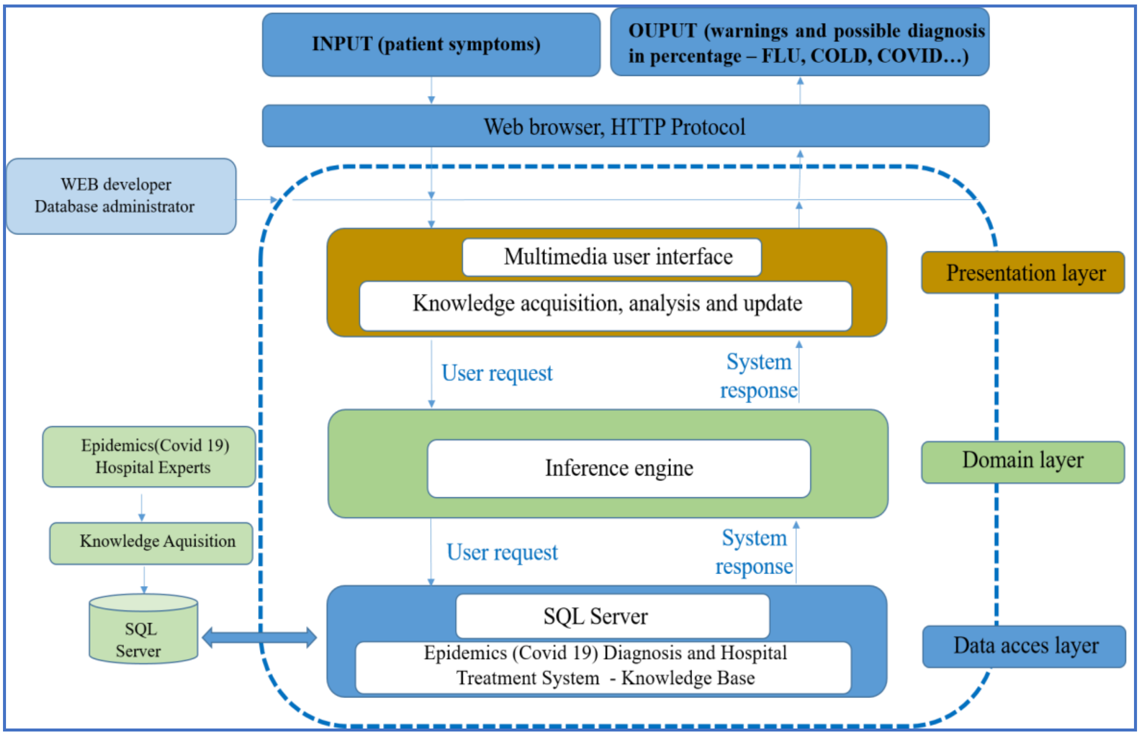

Figure 3. Self-diagnosis system (authors contribution)

3.1. Phases of implementation of the artificial intelligence-assisted Early Warning System for COVID-19 pandemic management

The pilot study of the artificial intelligence-assisted Early Warning System for the management of COVID-19 pandemic has 4 phases:

Phase 1: Construction of an information system in the form of responsive web platforms, which can be accessed from mobile phones/tablets/computers.

Phase 2: The web application accesses databases with profile cases diagnosed up to time T from hospitals dealing with pandemic treatment.

Phase 3: Ordinary users of the application fill in a questionnaire with their age, sex, and perceived symptoms. The questionnaire with perceived symptoms has up to 10 questions such as fever, cough, headache, fatigue, difficulty breathing etc., symptoms that are found in confirmed cases in hospitals. Users are also questioned about the existence of co-morbidities, such as hypertension, diabetes, obesity, etc.

Phase 4: A machine learning algorithm will be trained to compare the data from phases 2 and 3, the symptoms introduced by users with the diagnosed and treated cases. The learning base, from which the decision is made, is a medical base, with triage diagnoses confirmed by the doctors from the hospitals that provided the database.

Note: To be effectively implemented, the occupancy rate of hospitals dealing with pandemic patients must be permanently updated, both as percentage and numbers.

3.2. Operating principle of building, training and validating an artificial intelligence-assisted Early Warning System for COVID-19 pandemic management

The training and testing data set is to obtained through the acquisition of data from the virology & immunology hospitals i.e. raw data input and outcome variable for each individual tested and confirmed positive for COVID-19 (see Figure 4). Then, the next step in building, training and validating an algorithm for the early warning system is represented by the "Data pre-processing step", which consists of:

- Missing data imputation.
- Data re-balancing.
- Harmonization.
- Data cleansing.
- Dimensionality reduction.

The next step of the model is represented by "Training step", which consist of (see Figure 4):

- Learning methods.
- Regression and classification methods.

The common learning algorithms used for the training step are: support learning algorithms, k-nearest neighbor, artificial neuronal network, decision trees, ensemble methods, logistic regression, naive Bayes, random forests, gradient boosting and deep learning.

The common feature selection algorithms used are: lasso, elastic net, random forests, gradient boosting, support vector machine recursive feature elimination, correlation-based feature selection.

A continuous, bidirectional flow of processes takes place between the stage of "training" and "internal and external validation": discrimination and calibration, leave-one-out, cross-validation. The outcome of the early warning system based on artificial intelligence is given by the "best warnings and predictors" that underlie the proposed "early warning prediction model".

The proposed "early warning prediction model" receives real-time data through the application interface from application users, guided by the form with the symptoms that each individual must complete.

The result of comparing the confirmed data from COVID-19 hospitals with data provided by the ordinary users of the platform could give the authorities warnings and the predicted outcome as (see Figure 4):

- Pandemic/epidemic risk prediction.
- Percentage epidemic classification.
- Possible diagnosis.

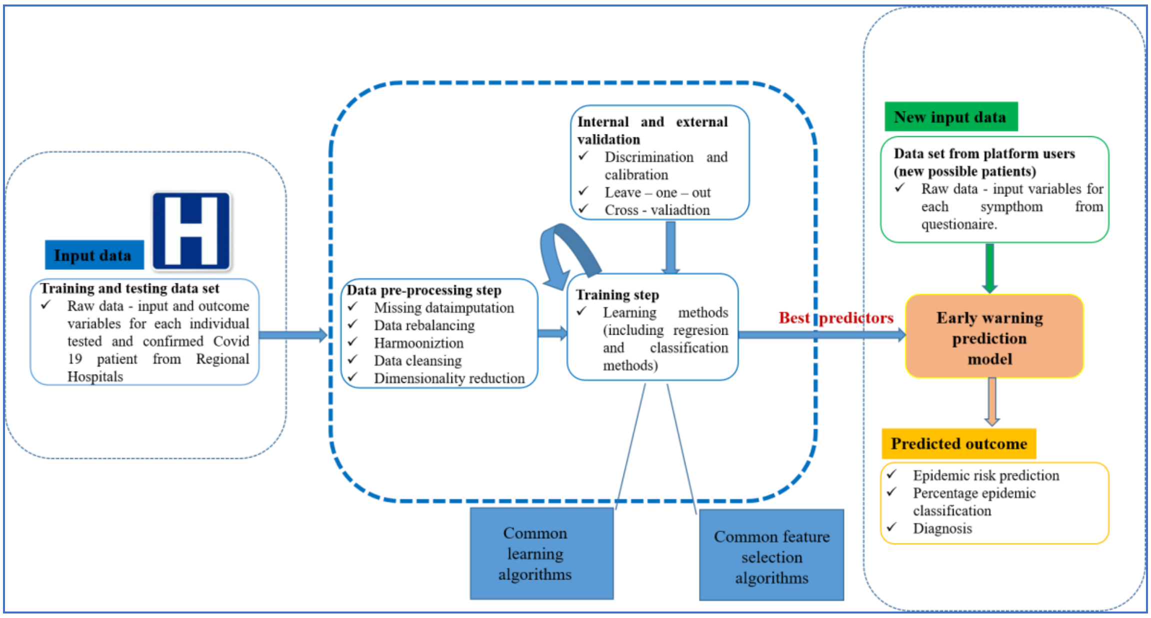

Figure 4. Operation principle of EWS (authors contribution)

4. Discussions

EWS is not intended to replace the test performed by doctors, because only they can tell if it is white or black, but it can estimate how close a person is to one diagnosis or another. And those who have the least dangerous symptoms will be advised to stay home, because the medical system will probably be very busy with people who, indeed, need to be treated. Seeing the rate of growth and diagnosis, the algorithm will be able to indicate for instance that the hospital will probably reach the maximum number of admissions in 15 days. In this way, EWS can ease pressure on doctors and the medical system.

The critical point of this project is to have good quality data confirmed by doctors in hospitals, without which the algorithm will not be able to provide the desired results. Also, the precision and accuracy of the pilot project is dependent on the amount of data it works with. The more data the EWS has from the health system, the more accurate and efficient it becomes.

5. Conclusion

EWS assisted by a machine learning algorithm can provide ordinary users with one of the following scores:

- … % the pacient may have the flu;
- … % the pacient may have a cold;
- and, … % the pacient may have other viruses, as COVID-19.

Although further research is needed to validate our model, it is promising as a tool to indicate the most vulnerable patients to the virus, as a support for physicians' clinical experience in treating viral infections.

We are certain that this method, when completed, will be useful to physicians to assess which patients with moderate disease should be hospitalized and which patients with the same condition can be sent home to save hospital resources.

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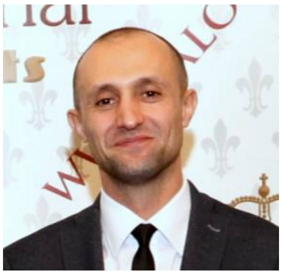

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