Fuzzy Logic Based Approach to Early Diagnosis of Ebola Hemorrhagic Fever

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Abstract— **In recent past, Ebola Hemorrhagic Fever (EHF) took a devastating toll on humanity, with its outbreak in mostly some West African countries, and with up to 90% mortality rate for those affected. As a result of the highly infectious nature of the ailment, there is urgent need for effective, accurate and fast diagnostic procedures. In this study, a Fuzzy Logic based approach is proposed, which is considered suitable for diagnosing EHF, especially at the early stage, before it becomes contagious. The system obtains responses (in linguistic terms) to symptoms such as, temperature, vomiting, bleeding, diarrhea, muscle pain, etc. from people suspected of being infected with the Ebola virus. It processes these responses using fuzzy classification approach to determine the possibility of Ebola virus infection. The advantage of this system is that, besides providing quick response alternative to the long period manual laboratory diagnosis, it also helps to reduce the likelihood that an un-infected person is quarantined or subjected to laboratory processes. It will aid early detection, thereby reducing further spread of the virus as well as mortality rate and stigmatization.**

Index Terms— Ebola Virus, Ebola Hemorrhagic Fever, Medical Diagnosis, Fuzzy Logic, Diagnosis of EHV.

I. Introduction

Ebola virus is a member of the Filoviridae viral family of RNA viruses, which are characterized by the long, thin filaments seen in micrograph images. It is named after the Ebola River where the virus was first discovered. Ebola virus was first isolated in 1976 during outbreaks of Ebola hemorrhagic fever in the Democratic Republic of Congo [21].

The virus causes Ebola Hemorrhagic Fever (EHF), which is a serious and usually fatal disease for those who contract it. It damages the endothelial cells that make up the lining of the blood vessels and creates difficulty in coagulation of the infected individual's blood. As the vessel walls become more damaged, and the platelets cannot coagulate, the individual undergoes hypovolemic shock, or a dramatic decrease in blood pressure. Depending on the type of virus, Ebola can have up to a 90 percent mortality rate for those infected. Until the 2014 outbreak, Ebola hemorrhagic fever was reported in humans only in Africa.

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Symptoms of Ebola Virus Disease (EVD) starts two days to three weeks after contracting the virus. Symptoms include fever, sore throat, muscle pain, headaches, vomiting, diarrhea, and rash, follow with decreased functioning of the liver and kidneys. Around this time, affected people may begin to bleed both within body and externally.

It is noted that health-care workers are at risk of infection when caring for EVD patients, if they do not wear adequate personal protection equipment (PPE) and if they do not follow strictly, the recommended measures for infection prevention and control. Other risks for workers involved in health care and epidemic response to EVD include psychological distress, stigma, violence, long working hours, heat stress, and dehydration from using heavy personal protection equipment (PPE) and ergonomic problems from handling bodies and loads. These require specific measures for psychosocial support, security and work organization [21].

It is observed that health workers are at the highest risk of being infected with Ebola virus disease even with their protective clothing because they are most certainly the primary contacts to infected patients. This also puts the family members and close associates of health workers at great risk of infection. In addition to the high fatality rate of Ebola virus, some other ailments present similar symptoms, coupled with fear of stigma and social rejection that come to patients and families when a diagnosis of Ebola is confirmed. There is urgent need for effective, accurate and fast diagnosis procedures. This will facilitate early management and quarantine process of infected patients. The need to evolve computer assisted processes for effective diagnosis becomes crucial in order to speed up the process of analyzing clinical data.

According to the report, 1 of 5 Health workers is prone to the disease because they are the first point of call for somebody who is sickened by disease. Even with the full protective clothing they put on, they are at risk. More than half of the 3,069 people infected by Ebola have died from the disease, which has spread across Sierra Leone, Liberia, Guinea, Nigeria and now Senegal.

The World Health Organization has warned the current outbreak could infect up to 20,000 people before it ends.

The aim of this study therefore is to model a computer-based Ebola diagnostic system, that uses fuzzy logic to analyze clinical data for the diagnosis of EHF.

This system will be of immense benefit to medical doctors and other health workers who will speedily get results that will enable them take immediate appropriate actions that will help reduce the risk of infection. The early detection will facilitate quarantine process, thereby reducing the risk of the wide spread of the Ebola Hemorrhagic fever and possibly reduce possibility of epidemic.

II. BACKGROUND TO THE STUDY

A. *Ebola Hemorrhagic Fever (EHF)*

There has been a lot of work on the outbreak of EHF and the operations of fuzzy logic in diagnosing viruses. [19] wrote about the origins and incidents involving viral hemorrhage fevers, particularly Ebola viruses and Marburg-viruses.

The filoviruses; Ebola Virus (EBOV), Sudan Virus (SUDV), Marburg virus (MARV), and Raven Virus (RAVV) are bio-safety level 4 agents. Bio-safety level agents are extremely dangerous to humans because they are very infectious, have a high case-fatality rate and there are no known preventions, treatment, or cure. Along with describing the history of the diseases caused by these two central African viruses, Ebola Virus disease and Marburg Virus disease, [19] describes a 1989 incident in which a relative of Ebola Virus named Reston Virus was discovered at a primate quarantine facility in Reston, Virginia, less than fifteen miles (24km) away from Washington, DC. The Virus found at the facility was mutated form of the original EHF, and was initially mistaken for Simian Hemorrhagic Fever (SHV).

Medicine is the science of intervention. Among human activities, medicine is competed only by agriculture and more recently by modern engineering in its capacity for changing the natural cause of human fate. To intervene, however, one must predict. To predict the natural cause of a system in the absence of intervention and to predict what is going to happen to such a system after the proposed intervention. Prediction in turn is strongly dependent on the scientific foundation of the subject in question. Although medicine has been intervening in human diseases since the dawn of humanity (actually with rather questionable results) only very recently the scientific cornerstones of medicine have been laid down [8].

After several centuries, as a set of empirical practices, medicine damaged the natural history in the 19th century and only in the first half of the 20th century it over passed the epistemological threshold which is characterized by the application of formal logic and mathematics to the theoretical bases of diseases. Therefore the marriage between mathematics and medicine is very recent and it started rather timidly with works by the fathers of epidemiology. Scattered applications of mathematics in some biomedical areas were found in the literature until the early 1970s. Since then mathematical biology has changed a great deal. In medicine specifically, mathematical models have been developed for some diagnostic problems and to a great extent to epidemiological questions [2].

Ebola Hemorrhagic Fever (EHF) is a disease of humans and other primates caused by an Ebola virus. Symptoms start about two days after contacting the Virus, with a fever, sore throat, muscle pain, and headaches. Typically vomiting, diarrhea and rash follow along with decreased functioning of the liver and kidneys. Around this time, affected people may begin to bleed both within the body and externally.

In 1976, Ebola (named after the Ebola river in Zaire), first emerged in Sudan and Zaire. The first outbreak of Ebola (Ebola Sudan) infected over 284 people, with a mortality rate of 53%. A few months later, the second Ebola virus emerged from Yambuku, Zaire, Ebola-Zaire (EBOZ). Ebola-Zaire, with the highest mortality rate of any of the Ebola viruses (88%), infected 318 people. Despite the tremendous effort of experienced and dedicated researchers, Ebola's natural reservoir was never identified [6].

The third strain of Ebola, Ebola Reston (EBOR), was first identified in 1989 when infected monkeys were imported into Reston, Virginia from Mindanao in the Philippines. Fortunately, the few people who were infected with Ebola Reston never developed Ebola hemorrhagic fever (EHF). The last known strain of Ebola, Ebola Cotre-d'Ivoir (EBO-CI) was first discovered in 1994 when a female etiologist performing a necropsy on a dead chimpanzee from the Tai forest, Cote-d'Ivoire, accidentally infected herself during the necropsy.

The Virus may be acquired upon contact with blood or body fluids of an infected animal. Spreading through the air has not been documented in the natural environment. Fruit bats are believed to be a carrier and may spread the virus without being affected. Once human infection occurs, the disease may spread between people, as well. Male survivors may be able to transmit the disease via semen for nearly two months. To make the diagnosis, typically other diseases with similar symptoms such as malaria, cholera and other viral hemorrhagic fevers are first excluded. To confirm the diagnosis, blood samples are tested for anti-bodies, viral RNA or the virus itself [2].

Prevention includes decreasing the spread of disease from infected animals to humans. This may be done by checking such animal for infection and killing and properly disposing of the bodies if the disease is discovered. Properly cooking meat and wearing protective clothing and washing hands when around a person with the disease. Samples of bodily fluids and tissues from people with the disease should be handled with special caution and utmost care. No specific treatment for the diseases yet available. Efforts to help those who are infected are supportive and include giving either oral hydration therapy (slightly sweet and salty water to drink) or intravenous fluids [2].

The disease has a high risk of death, killing between 50% and 90% of those infected with the Virus. The World Health Organization [21], reported a total of 1,716 cases. The largest outbreak to date is the ongoing 2014, 3,069 suspected cases resulting in the deaths of 1,552 have been reported. Efforts are under way to develop a vaccine, however, none yet exists.

B. *Fuzzy Logic*

The term "fuzzy logic" was introduced with the 1965 proposal of fuzzy set theory by Lofti A. Zadeh. Fuzzy logic has been applied to many fields, from control theory to artificial intelligence. In mathematical logic, there are several formal systems of "fuzzy logic"; most of them belong among so-called t-norm fuzzy logics.

In a very simple term, fuzzy logic allows situations or problems to be described and processed in linguistic terms such as "hot" or "heavy" instead of precise numeric values such as "140 degrees" or "180kg". Fuzzy logic, in essence,

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allows one to view problems from a higher linguistic level, thereby enabling less complex problems to be solved. Because of the many advantages of such a linguistic system, the areas of application of fuzzy logic have spread from consumer electronics to industrial control, information processing, medicine, financial analysis and much more in just the past few years [20].

Fuzzy logic is a form of many-valued logic; it deals with reasoning that is approximate rather than exact. Compared to traditional binary sets (where variables may take on true or false values), fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true or completely false. Furthermore, when linguistic variables are used, these degrees may be managed by specific functions. Irrationality can be described in terms of what is known as the fuzzjective [16].

In terms of the early application, the Japanese were the first to utilize fuzzy logic for practical applications. The first notable application was on the high-speed train in Sendai, in which fuzzy logic was able to improve the economy, comfort and precision of the ride. It has also been used in recognition of hand written symbols in Sony pockets computers; flight aid for helicopters; controlling of subway systems in order to improve driving comfort, precision of halting and power economy, improved fuel consumption for automobiles, single-button control for washing machines, automatic motor control for vacuum cleaners with recognition of surface condition and degree of soiling and early recognition of earthquakes through the institute of Seismology Bureau of Metrology, Japan [20].

Fuzzy systems can be used to solve challenging problems related to medical, biomedical, and health fields. Fuzzy logic is an effective approach to represent knowledge. Medicals require medical knowledge to handle medical information using computer.

Firstly it defines inexact medical entities as fuzzy sets. Secondly, it provides a linguistic approach with an excellent approximation to texts. Finally, fuzzy logic offers reasoning methods capable of drawing approximate inferences.

Determination of Membership Degrees

Zadeh proposed a series of membership functions that could be classified into two groups: those made of straight lines or "linear" and Gaussian forms or "curves" [22].

The type of representation of the membership function depends on the base set. If the set consists of many values, or the base set is a continuum, then a parametric representation is appropriate. For that, functions are used that can be adapted by changing the parameters. Piecewise linear membership functions are preferred because of their simplicity and efficiency with respect to compatibility. These are mostly trapezoidal or triangular functions which are defined by four and three parameters respectively as shown in equation 1.

$$f(x;a,b,c,d) = \begin{cases} 0, & x \le a \\ \dfrac{x-a}{b-a}, & a \le x \le b \\ 1, & b \le x \le c \\ \dfrac{d-x}{d-c}, & c \le x \le d \\ 0, & d \le x \end{cases} \quad \dots \quad \dots \quad \text{Eqtn.1}$$

This migrates into a triangular function for the case b=c

For some applications the modeling requires continuously differentiable curves and therefore smooth transitions, which the trapezoids do not have.

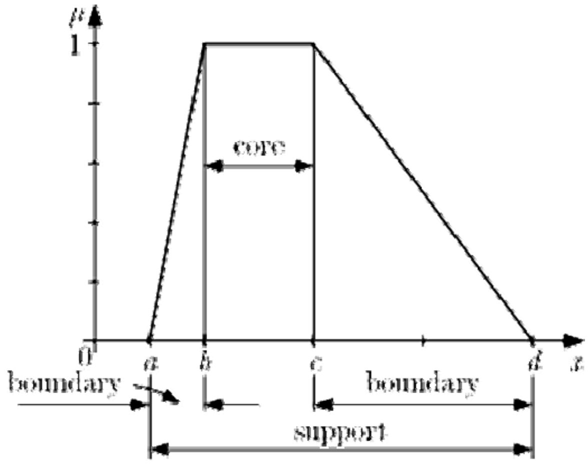

Figure 1: Illustration of trapezoidal function

C. Existing System of EHF Diagnosis

Investigations carried out on EHF shows that it is difficult to diagnose because early signs and symptoms resemble those of other diseases, such as typhoid and malaria. However, in outbreaks of EHF, infection is confirmed by various laboratory diagnostic methods. The diagnostic method is fractioned into some timelines which includes:

***Timeline 1*: Few Days After Symptom Begins.**

In this, the diagnostic tests available are as follows.

(1). Virus Isolation, reverse transcription polymerase chain reaction (RT-PCR) as commonly used in molecular biology for detecting RNA expression:

(2) Real-time polymerase chain reaction (RT-PCR), used to qualitatively detect gene expression through creation of complementary DNA from RNA.

(3). Antigen-capture enzyme-linked immunosorbent assay (ELISA): ELISA is a popular format of wet-lab type analytic biochemistry assay that uses a solid phase enzyme immunoassay (EIA) to detect the presence of a substance, usually an antigen, in a liquid sample or wet sample.

Timeline 2: Later in disease course / recovery

In this, the diagnostic tests available are as follows.

(1) IgM Antibodies: An immunoglobulin test measures the level of certain immunoglobulins, or antibodies, in the blood. Antibodies are proteins made by the immune system to fight antigens, such as bacteria, viruses, and toxins.

(2) IgG Antibodies: antigen detection by immunostaining, and IgG - and IgM-ELISA using authentic virus antigen. Histological techniques, including antigen

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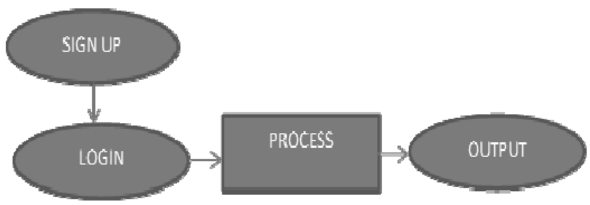
detection by immunohistochemical analysis, are sensitive methods, particularly for post-mortem diagnosis. Diagnosis by detection of virus antigens is suitable for patients in the early stage of illness, while serological diagnosis by the detection of specific IgM and IgG antibodies is suitable for patients in a relatively late stage of illness. The former is especially suitable for patients who die before an antibody response is mounted.

III. Modeling approach

The proposed system (application), consist of four main sections. The first section is the patient's bio data capture; the second section is the knowledge based diagnostic domain, the third section is the inference engine and the fourth section, the output.

The system design approach follows the traditional input, process and output design methodology.



. Figure 2: The process diagram

A. Methodology

After a careful study of the available relevant literature on EVD, it is observed that;

i. EVD is a lethal ailment and is highly infectious;

ii. Symptoms of the disease at early stage are similar to symptoms of some other ailments like malaria or typhoid fever;

iii. Diagnosis of EVD follows various laboratory diagnostic procedures. This may take as long as three weeks. In most cases, infected people may not be aware early enough, and may not report for medical attention in good time. This increases the risk of spread.

iv. The symptoms manifest along timelines, from the second day after contact with the virus till about twenty-one days when the disease manifests fully.

v. It is also noted that most people can express how they feel in plain language, such as, "no headache", "mild headache", "severe headache", or "very severe headache".

Following design science approach [9]; [15] and systems engineering hierarchy approach [18], we formulated innovative concepts and research idea that showed potential to improve actual clinical diagnostic capabilities. Fuzzy logic therefore promises a solution that can allow people respond to questions on each symptom, regarding how they feel in simple linguistic terms, which can be processed to get inference on possibility of EVD infection.

Input Requirements and Forms:

SignUp table: This is used to collect the patient's bio data. The entities include; Surname, Other names, Sex, Age, Date of birth, Place of birth, Nationality, Place of residence, Email, Phone, Contact address, Recent journeys, Username, Password.

Patient Registration: The input requirements here are the various data fields to be captured from the patient. The data collection interface is user friendly and captures the patient's bio data as well as responses to symptom's investigation.

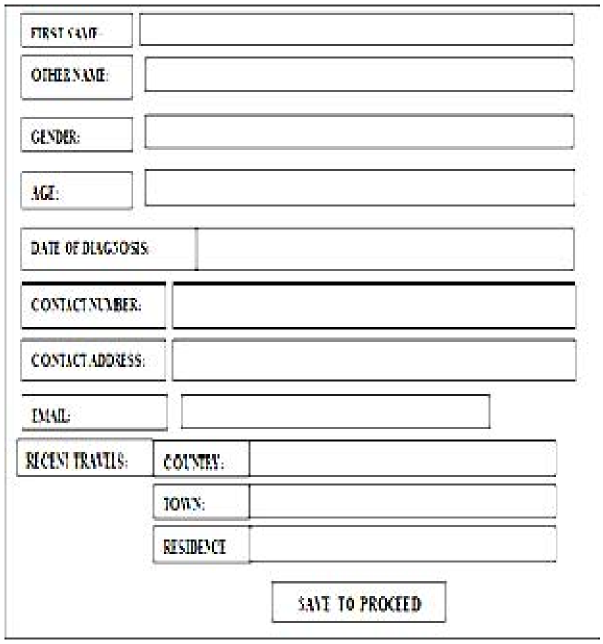


Figure 3: Bio Data Interface Design

Processing Design Consideration

The fuzzy logic based expert system modeled in this work is a rule based system that uses fuzzy logic rather than Boolean logic for decision making.

We illustrate the Fuzzy classification procedures as follows [10]:

Step 1: Determine the target attributes Tx. In this case the symptoms.

Step 2:Determine the class membership attributes (CMA) of the target attributes i.e class boundaries.

Step3: Specify the Fuzzy Classification for instance, none, mild, severe, very severe.

Step 4: Calculate the membership degree of each Tx, using the function

$\mu_{CMA}(Tx) \in [0,1]$ [22].

Step 5: Specify the Fuzzy Membership Table (FMT), which gives the degree to which a value is related to a membership class.

Integration of Fuzzy Concepts

The symptoms of EVD are classified into six categories using classical approach. However it is important to note that EVD symptoms do in actual fact belong to each of the class membership categories to certain degrees. For instance, initial syndrome may belong to mild category only to a certain degree and severe category again to a certain degree. This situation cannot be visualized using classical approach.

We specify the membership attributes with the following fuzzy set. Both input and output parameters selected are described with four linguistic variables as follows:

"None", "Mild", "Severe" and "Very Severe".

We set the class boundaries as shown in figure 2 and determine membership degree of each attribute the following function;

μ_{none}(diagvalue) = {if diagvalue<5, MD_ebolagrp=1
ifdiagvalue>=10, MD_ebolagrp=0
else if MD_ebolagrp=(20-diagvalue)/20-5)}

μ_{mild}(diagvalue)={if diagvalue>=5 AND <10, MD_ebolagrp=1
ifdiagvalue<5, MD_ebolagrp=0
ifdiagvalue>15, MD_ebolagrp=0
else if 10<= diagvalue<=15,
MD_ebolagrp=(diagvalue – 5)/(20-5)
Else if 15<=diagvalue<=20,
MD_ebolagrp=(perf_Score-20/25-20)}

μ_{severe}(diagvalue)={if diagvalue>=10 AND <15, MD_ebolagrp=1
ifdiagvalue<5, MD_ebolagrp=0
ifdiagvalue>20, MD_ebolagrp=0
else if 5<= diagvalue<=10,
MD_ebolagrp=(diagvalue – 5)/(10-5)
Else if 15<=diagvalue<=20,
MD_ebolagrp=(diagvalue-15/25-20)}

μ_{very_severe}(diagvalue)={if diagvalue>=15 AND <20, MD_ebolagrp=1
ifdiagvalue<10, MD_ebolagrp=0
ifdiagvalue>25, MD_ebolagrp=0
else if 10<= diagvalue<=15,
MD_ebolagrp=(diagvalue –10)/(25-10)
MD_ebolagrp=(diagvalue -20/25-20)}
Else if 20<=diagvalue<=25,

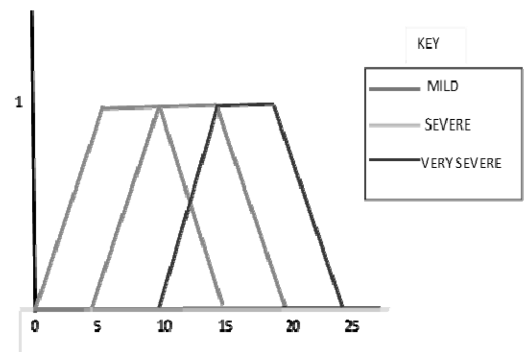


Figure 4: Example of fuzzy membership graph

We identify the target attributes which may assume any of the variables above as a value.

Table 1: Classification of EHF symptoms

A. Initial Syndrome • Fever • Chills • Fatigue • Headache • Vomiting • Diarrhea • Loss of Appetite	B. Hemorrhage • Blood in Stool • Petechial Bleeding Spot • Oozing from vein puncture sites • Mucosal Bleeding
C. Rashes • Skin Redness • Face Region • Neck Region • Trunk Region • Arms Region	D. Neurologic • Altered level of Consciousness • Stiff Neck • Seizures
E. Gastrointestinal Signs • Watering Diarrhea • Nausea • Vomiting • Abdominal Pain • Dehydration • Shock	F. Other Signs • Hiccups • Chest Pain • Shortness of Breath • Dark red discoloration of the soft palate

We set the linguistic variables and corresponding weights

Table 2: Linguistics Variables Weight Table

Variables	Weights
None	0
Mild	1
Severe	2
Very Severe	3

Next we specify the class boundaries table.

Table 3: Class Boundaries Table

Terms	a	b	c	d
Mild	0	5	10	15
Severe	5	10	15	20
Very Severe	10	15	20	25

We carry out a sample diagnosis using the four variable input criteria

Table 4: Sample Diagnosis values

Name	Fever	Chills	Fatigue	Head-ache	Vomit-ing	Diarrhea	Loss of Appetite
Patient1	None	Mild	Severe	None	Mild	Sev-ere	Severe
Patient2	Mild	Mild	Severe	Mild	Very Severe	Mild	Severe
Patient3	Severe	**None**	Severe	Mild	None	Mild	None

The Weighted diagnosis values derived from Table 4 are shown in table 5.

Table 5: Diagnosis Values

Name	Fever	Chills	Fatigue	Headache	Vomiting	Diarrhea	Loss of Appetite	Diagnosis Value
Patient 1	0	1	2	0	1	2	2	8
Patient 2	1	1	2	1	3	1	2	11
Patient 3	2	0	2	1	0	1	0	6

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We use the computed diagnosis values to determine the membership degrees for each of the variables as shown in table 6.

Table 6: The Fuzzy Classification Table (e.g. Initial Syndrome).

Name	Diagnosis Value	None	Mild	Severe	Very Severe	Inference
Patient 1	8	0	1	0.6	0	Observe Patient, Repeat in 24 hours
Patient 2	11	0	0.8	1	0.2	Quarantine, Treat and repeat in 24 hours
Patient 3	6	0	1	0.2	0	Observe, Treat for fever and repeat in 48 hours

This same procedure is iterated for the other five symptoms categories.

B. Conclusion

In this work, we have specified an approach for the design of EHF diagnostic system using fuzzy logic. This system is a computer program which is designed to model a life situation of artificial intelligence using the vast resources of the computer system. This system obtains symptoms such as temperature, vomiting, bleeding, diarrhea, muscle pain to instantly diagnose EHF. The advantage of this system is that it accepts input from suspected patients in plain linguistic terms and processes these responses to draw inference on EVD status of the person. This will offer quick diagnosis and follow up of people who have visited Ebola infected places. The system can also be deployed on hand held mobile devices like phones and tablets. With its use, the possibility that wrong persons are quarantined or that infected persons are detected too late is greatly reduced. It is therefore an invaluable resource to complement the manual laboratory diagnosis of Ebola which takes three weeks to detect. The developed application will help to reduce mortality rate of Ebola patients as the ailment will be diagnosed as quickly as possible and appropriate drugs will be administered to the patient.

While further work is ongoing to produce software using this approach, we also encourage other developers to use this approach produce an EHF diagnostic application with enhanced efficiency and reliability.

C. Further Studies.

Further work is being done on the use of this approach to develop a software, especially for hand-held devices.

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