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Original Article

Malaria detection using mathematical theory of evidence

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Abstract

Malaria is still one of the most common infectious diseases in the world and one of the greatest global public health problems in many parts of the world. The existing methods used to detect malaria are complicated, an extremely time-consuming process, and can only be performed under laboratory conditions, often require highly trained lab workers and time-intensive procedures, as well as a highly sterile experimental environment. This research is an assessment on the effectiveness of Dempster-Shafer's mathematical theory of evidence. Six different conditions of malaria detection are proposed. The result reveals that malaria detection using Dempster-Shafer theory obtained degrees of belief of 88% for condition 1, 82% for condition 2, 80% for condition 3, 92% for condition 4, 97% for condition 5, and 98.6% for condition 6.

Keywords: malaria, disease detection, theory of evidence

1. Introduction

Based on the Malaria Fact Sheet Report 2015 released by World Health Organization (WHO) reported that about 3.2 billion people, almost half of the world's population, are at risk of malaria (WHO, 2015). The international agenda shaping malaria control financing, research, and implementation is increasingly defined around the goal of regional elimination (Chitnis *et al.*, 2010; Tanner *et al.*, 2010; Moonen *et al.*, 2010). Nantavisai (Nantavisai, 2014) summarized the techniques that have been used to detect malaria in non-blood samples. Numerous approaches exist for malaria detection include LAMP (Loop mediated isothermal amplification) (Han, 2013; Singh *et al.*, 2013; Najafabadi *et al.*, 2014), ELISA (Chidi *et al.*, 2010; Estevez *et al.*, 2011; Fung *et al.*, 2012) and PCR (Pooe *et al.*, 2011; Putaporntip *et al.*, 2011; Singh *et al.*, 2014). The existing methods used to detect malaria are complex, time consuming, and can only be performed under laboratory conditions, and often require highly trained lab workers and time-intensive procedures, as well as a highly sterile experimental environment.

Malaria is a mosquito-borne infectious disease of humans and other animals caused by parasitic protozoans belonging to the genus Plasmodium (WHO, 2015). Early diagnosis of disease is important in interrupting the transmission cycle of the parasite and progress of the disease to the late stage. Therefore, cost effective, simple, rapid, robust and reliable methods, are urgently needed. There is also an urgent need for accurate tools for the diagnosis of malaria, a new initiative for the development of new diagnostic tests to support the control of malaria. The mathematical theory of evidence is designed to deal with the distinction between uncertainty and ignorance, and allows quantitative measurement of the belief and plausibility in the identification result (Stuart *et al.*, 2002, Wang, 1998; Shafer, 1976). The remainder of the paper is organized as follows: mathematical theory of evidence applied to malaria detection is presented in section 2, implementation of malaria detection using mathematical

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theory of evidence is presented in section 3, result and discussions are presented in section 4, and conclusions are presented in section 5.

2. Mathematical Theory of Evidence to Malaria Detection

The mathematical theory of evidence or Dempster-Shafer theory can be implemented as a generalization of probability theory (Dempster, 1967; Dempster, 1968; Shafer, 1976). The Dempster-Shafer theory (Shafer, 1976) assumes that there is a fixed set of mutually exclusive and exhaustive elements called hypotheses or propositions and symbolized by the Greek letter Θ. Θ = {Disease 1, Disease 2,... , Disease n}, where symptom is called a hypothesis or propositions. A hypothesis can be any subset of the frame, for example, from singletons in the frame to combinations of elements in the frame. Θ is also called the frame of discernment (Shafer, 1976). A basic probability assignment (bpa) is represented by a mass function m: $2^{\Theta} \rightarrow [0,1]$ (Shafer, 1976). Where 2Θ is the power set of Θ. The sum of all basic probability assignment of all subsets of the power set is 1 as shown in equation 2, which embodies the concept that total belief has to be one (Yager, 1986). The value of the bpa for a given set A (represented as m(A), $A \in 2^{\Theta}$, expresses the proportion of all relevant and available evidence that supports the claim that a particular element of Θ (the universal set) belongs to the set A but to no particular subset of A. The value of m(A) pertains only to the set A and makes no additional claims about any subsets of A. Any further evidence on the subsets of A would be represented by another bpa, in example B, m(B) would the bpa for the subset B. Formally, this description of m can be represented with the following two equations 1 and 2 (Shafer, 1976):

$$m(\varnothing) = 0 \tag{1}$$

$$\sum_{A \in 2^{\theta}} m(A) = 1 \tag{2}$$

From the mass function, the upper and lower bounds of an interval can be defined. This interval contains the precise probability of a set of interest and is bounded by two non additive continuous measures called Belief function and Plausibility function. Evidence theory uses two measures of uncertainty, belief function and plausibility function, expressed as Bel() and Pls() respectively. Given a basic probability assignment, m, the corresponding belief function measure and plausibility function measure are determined for all sets $A \in 2^{\Theta}$ and $B \in 2^{\Theta}$. by equations 3 and 4 (Shafer, 1976):

$$Bel(A) = \sum_{B \subseteq A} m(B) \tag{3}$$

$$Pls(A) = \sum_{B \cap A \neq \varnothing} m(B) \tag{4}$$

The support function or belief, Bel, is the total belief of a set and all its subsets. The lower bound Belief for a set A is defined as the sum of all the basic probability assignments of the proper subsets (B) of the set of interest (A). The plausibility function of a proposition, Pls, is the sum of the masses of all propositions in which it is wholly or partially contained. The plausibility function is defined as the degree to which the evidence fails to refute A. These two functions, which have been sometimes referred to as lower and upper probability functions, have the following properties are given by equations 5 and 6 (Shafer, 1976):

$$\mathrm{Bel}(A) \leq \mathrm{Pls}(A) \tag{5}$$

$$\mathrm{Pls}(A) = 1 - \mathrm{Bel}(\bar{A}) \tag{6}$$

Where $\bar{A}$ is the complementary hypothesis of A, $A \cup \bar{A} = \Theta$ and $A \cap \bar{A} = \varnothing$. The plausibility Pls (A) is defined as the degree to which the evidence fails to refute A. This term is given by the equation 7 (Shafer, 1976):

$$Pls(A) = 1 - Bel(\bar{A}) = 1 - \sum_{B \subseteq \bar{A}} m(B) \tag{7}$$

Dempster-Shafer theory provides a method to combine the previous measures of evidence of different sources (Shafer, 1976). This rule assumes that these sources are independent. Dempster's rule of combination (Shafer, 1976), given in equation 8 below.

$$(m_1 \oplus m_2)(A) = \begin{cases} 0 \\ \dfrac{\sum_{B_i \cap B_j = A} m_1(B_i) m_2(B_j)}{1 - \sum_{B_i \cap B_j = \varnothing} m_1(B_i) m_2(B_j)} & ; A \neq \varnothing \end{cases} \tag{8}$$

Where $A \in 2^{\theta}, B_i \in 2^{\theta}$ and $B_j \in 2^{\theta}$

3. Implementation

In this implementation, six different conditions of malaria detection are proposed. Assume that the basic probability assignments of six different conditions of malaria detection in which already known is available as shown in Table 1.

Malaria detection describes five symptoms which include malaise, fever, nausea, vomitting, and headache. The following will shown the process of malaria detection using mathematical theory of evidence.

3.1 Symptom 1 is malaise

Malaise is a symptom of malaria {M}, gastroentritis {G}, and lyme disease {LD}.

m_1 {M, G, LD} = 0.7

m_1 {Θ} = 1–0.7 = 0.3

3.2 Symptom 2 is fever

Fever is a symptom of malaria {M}, influenza {I}, gastroentritis {G}, and lyme disease {LD}.

Table 1. Basic probability assignments of symptom of malaria

Symptom	Disease	Basic Probability Assignment					
		Condition 1	Condition 2	Condition 3	Condition 4	Condition 5	Condition 6
Malaise	Malaria Gastroentritis Lyme Disease	0.7	0.6	0.8	0.5	0.9	0.4
Fever	Malaria Influenza Gastroentritis Lyme Disease	0.5	0.8	0.7	0.4	0.6	0.5
Nausea	Malaria	0.8	0.4	0.5	0.6	0.7	0.9
Vomitting	Malaria	0.4	0.7	0.6	0.8	0.5	0.8
Headache	Malaria Influenza Gastroentritis Lyme Disease	0.6	0.5	0.4	0.7	0.8	0.7

$m_2\{M, I, G, LD\} = 0.5$
$m_2\{\Theta\} = 1–0.5 = 0.5$

Table 2 shows The first combination of malaria detection

The first two bpas m_1 and m_2 are calculated to yield a new bpa m_3 by a combination rule as follows

$m_3\{M, G, LD\} = 0.35+0.35/(1\text{-}0) = 0.7$
$m_3\{M, I, G, LD\} = 0.15/(1\text{-}0) = 0.15$
$m_3\{\Theta\} = 0.15/(1\text{-}0) = 0.15$

3.3 Symptom 3 is nausea

Nausea is a symptom of malaria {M}.

$m_4\{M\} = 0.8$
$m_4\{\Theta\} = 1–0.8 = 0.2$

Table 3 shows the second combination of malaria detection

The first two bpas m_3 and m_4 are calculated to yield a new bpa m_5 by a combination rule as follows

$m_5\{M\} = 0.56 + 0.12 + 0.12/(1\text{-}0) = 0.80$
$m_5\{M, G, LD\} = 0.14/(1\text{-}0) = 0.14$
$m_5\{M, I, G, LD\} = 0.03/(1\text{-}0) = 0.03$
$m_5\{\Theta\} = 0.03/(1\text{-}0) = 0.03$

3.4 Symptom 4 is vomitting

Vomitting is a symptom of malaria {M}.

$m_6\{M\} = 0.4$
$m_6\{\Theta\} = 1–0.4 = 0.6$

Table 4 shows the third combination of malaria detection

The first two bpas m_5 and m_6 are calculated to yield a new bpa m_7 by a combination rule as follows

$m_7\{M\} = 0.32 + 0.056 + 0.012 + 0.012 + 0.48/(1 – 0) = 0.88$
$m_7\{M, G, LD\} = 0.084/(1 – 0) = 0.084$
$m_7\{M, I, G, LD\} = 0.018/(1 – 0) = 0.018$
$m_7\{\Theta\} = 0.018/(1\text{-}0) = 0.01$

3.5 Symptom 5 is headache

Headache is a symptom of malaria {M}, influenza {I}, gastroentritis {G}, and lyme disease {LD}.

$m_8\{M, I, G, LD\} = 0.6$
$m_8\{\Theta\} = 1–0.6 = 0.4$

Table 5 shows the fourth combination of malaria detection

Table 2. The first combination of malaria detection

	$m_2(\{M, I, G, LD\}) = 0.5$	$m_2(\{\Theta\}) = 0.5$
$m_1(\{M, G, LD\}) = 0.7$	$\{M, G, LD\} = 0.35$	$\{M, G, LD\} = 0.35$
$m_1(\{\Theta\}) = 0.3$	$\{M, I, G, LD\} = 0.15$	$\{\Theta\} = 0.15$

Table 3. The second combination of malaria detection

	$m_4(\{M\}) = 0.8$	$m_4(\{\Theta\}) = 0.2$
$m_3(\{M, G, LD\}) = 0.7$	$\{M\} = 0.56$	$\{M, G, LD\} = 0.14$
$m_3(\{M, I, G, LD\}) = 0.15$	$\{M\} = 0.12$	$\{M, I, G, LD\} = 0.03$
$m_3(\{\Theta\}) = 0.15$	$\{M\} = 0.12$	$\{\Theta\} = 0.03$

Table 4. The third combination of malaria detection

	$m_6(\{M\}) = 0.4$	$m_6(\{\Theta\}) = 0.6$
$m_5(\{M\}) = 0.80$	$\{M\} = 0.32$	$\{M\} = 0.48$
$m_5(\{M, G, LD\}) = 0.14$	$\{M\} = 0.056$	$\{M, G, LD\} = 0.084$
$m_5(\{M, I, G, LD\}) = 0.03$	$\{M\} = 0.012$	$\{M, I, G, LD\} = 0.018$
$m_5(\{\Theta\}) = 0.03$	$\{M\} = 0.012$	$\{\Theta\} = 0.018$

Table 5. The fourth combination of malaria detection

	$m_8(\{M, I, G, LD\}) = 0.6$	$m_8(\{\Theta\}) = 0.4$
$m_7(\{M\}) = 0.88$	$\{M\} = 0.528$	$\{M\} = 0.352$
$m_7(\{M, G, LD\}) = 0.084$	$\{M, G, LD\} = 0.05$	$\{M, G, LD\} = 0.034$
$m_7(\{M, I, G, LD\}) = 0.018$	$\{M, I, G, LD\} = 0.011$	$\{M, I, G, LD\} = 0.007$
$m_7(\{\Theta\}) = 0.01$	$\{M, I, G, LD\}\ 0.011$	$\{\Theta\} = 0.007$

The first two bpas m_7 and m_8 are calculated to yield a new bpa m_9 by a combination rule as follows

$m_9\{M\} = 0.52 + 0.352/(1\text{-}0) = 0.88$

$m_9\{M, G, LD\} = 0.05 + 0.034 / (1\text{-}0) = 0.084$

$m_9\{M, I, G, LD\} = 0.011 + 0.007 + 0.011 / (1\text{-}0) = 0.029$

$m_9\{\Theta\} = 0.007/(1\text{-}0) = 0.007$

Finally, the final ranking of the degree of belief is 0.88 > 0.084 > 0.029. The final ranking is Malaria > Malaria, Gastroentritis, Lyme Disease > Malaria, Influenza, Gastroentritis, Lyme Disease. Disease is malaria. Figure 1 shows detection of malaria. Figure 2 shows the result of malaria detection.

4. Results and Discussion

The aim of this research was to detect malaria using mathematical theory of evidence. Six different conditions of malaria detection are proposed. An implementation of applying mathematical theory of evidence in solving a malaria detection problem shows that it does improve the decision results.

In condition 1, the final ranking of the degree of belief is 0.88 > 0.084 > 0.029. It can be seen from Figure 3 that the final ranking is Malaria > Malaria, Gastroentritis, Lyme Disease > Malaria, Influenza, Gastroentritis, Lyme Disease.

In condition 2, the final ranking of the degree of belief is 0.82 > 0.108 > 0.065. It can be seen from Figure 4 that the final ranking is Malaria > Malaria, Gastroentritis, Lyme Disease > Malaria, Influenza, Gastroentritis, Lyme Disease.

In condition 3, the final ranking of the degree of belief is 0.80 > 0.16 > 0.033. It can be seen from Figure 5 that the final ranking is Malaria > Malaria, Gastroentritis, Lyme Disease > Malaria, Influenza, Gastroentritis, Lyme Disease.

In condition 4, the final ranking of the degree of belief is 0.92 > 0.04 > 0.033. It can be seen from Figure 6 that the final ranking is Malaria > Malaria, Gastroentritis, Lyme Disease > Malaria, Influenza, Gastroentritis, Lyme Disease.

In condition 5, the final ranking of the degree of belief

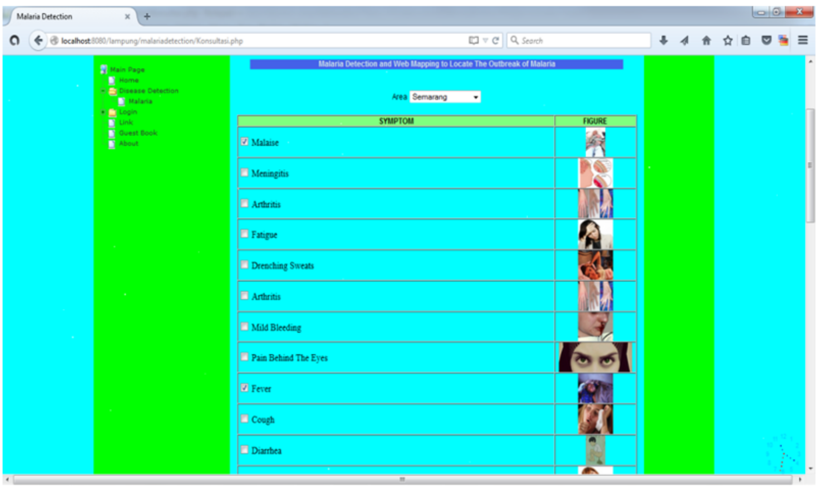

Figure 1. Malaria detection

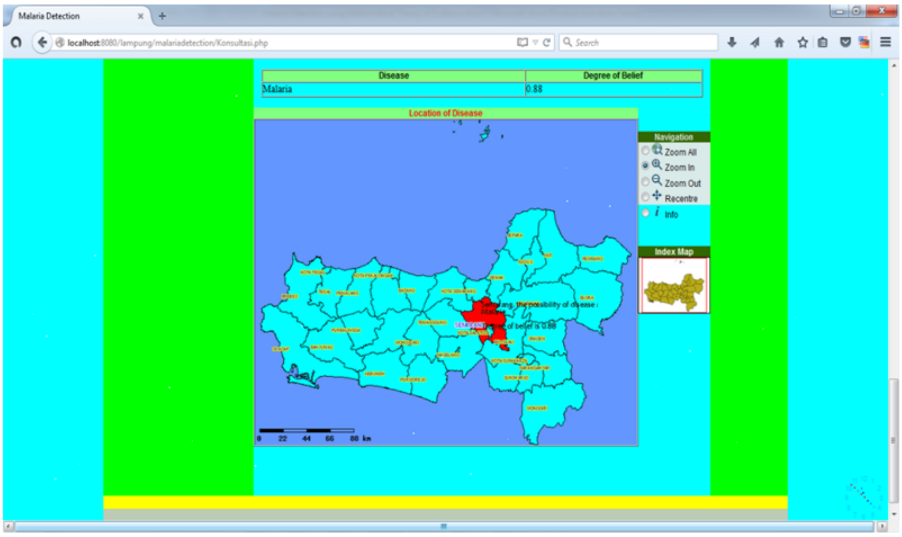

Figure 2. Result of malaria detection

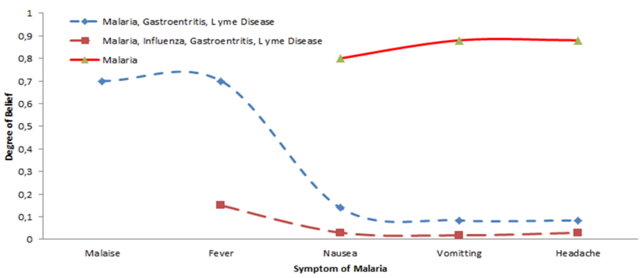

Figure 3. Condition 1 of malaria detection

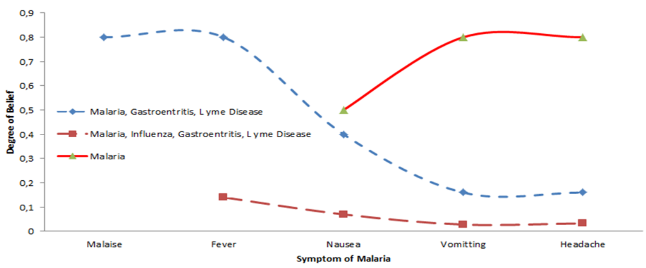

Figure 5. Condition 3 of malaria detection

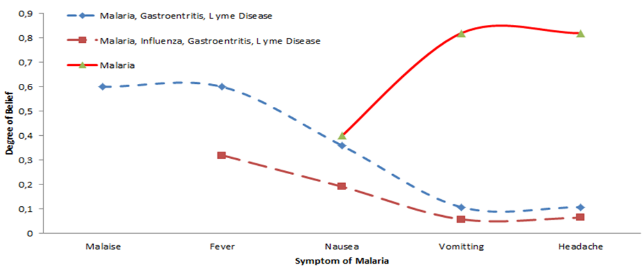

Figure 4. Condition 2 of malaria detection

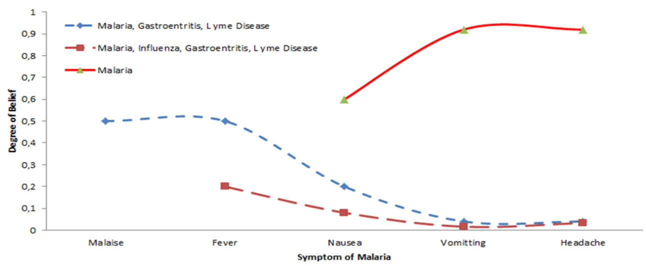

Figure 6. Condition 4 of malaria detection

is 0.97 > 0.027 > 0.002. It can be seen from Figure 7 that the final ranking is Malaria > Malaria, Influenza, Gastroentritis, Lyme Disease > Malaria, Gastroentritis, Lyme Disease.

In condition 6, the final ranking of the degree of belief is 0.986 > 0.01 > 0.002. It can be seen from Figure 8 that the final ranking is Malaria > Malaria, Influenza, Gastroentritis, Lyme Disease > Malaria, Gastroentritis, Lyme Disease. Figure 9 shows degree of belief of malaria detection.

5. Conclusions

The mathematical theory of evidence has attracted considerable attention as a promising method of dealing with the malaria detection problem arising with combination of evidence. The knowledge is uncertain in the collection of basic events and can be directly used to draw conclusions in simple cases. However, in many cases the various events are associated with each other. Reasoning under uncertainty that uses some mathematical expressions give them a different interpretation in which each piece of evidence may support a subset containing several hypotheses. This is a generalization of the pure probabilistic framework in which every finding corresponds to a value of a variable. In this research, condition 1 of malaria detection obtained a degree of belief of 88% for Malaria, 8.4% for Malaria, Gastroentritis, Lyme Disease and 2.9% for Malaria, Influenza, Gastroentritis, Lyme

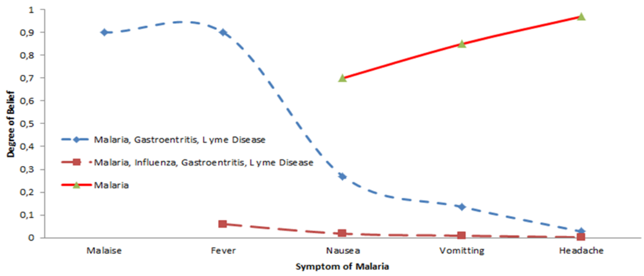

Figure 7. Condition 5 of malaria detection

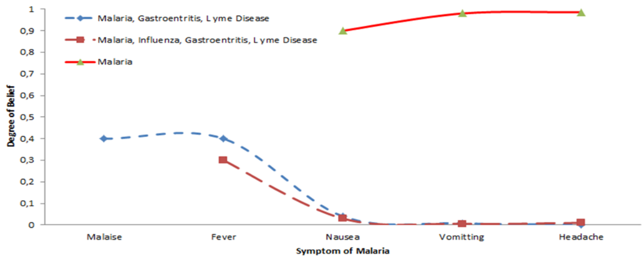

Figure 8. Condition 6 of malaria detection

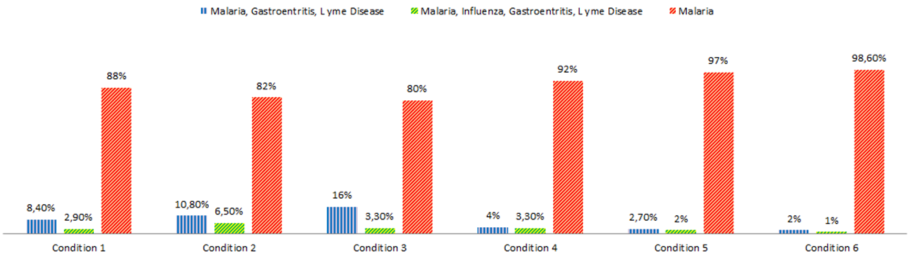

Figure 9. Degree of belief of malaria detection

Disease. Condition 2 of malaria detection obtained a degree of belief of 82% for Malaria, 10.8% for Malaria, Gastroentritis, Lyme Disease and 6.5% for Malaria, Influenza, Gastroentritis, Lyme Disease. Condition 3 of malaria detection obtained a degree of belief of 80% for Malaria, 16% for Malaria, Gastroentritis, Lyme Disease and 3.3% for Malaria, Influenza, Gastroentritis, Lyme Disease. Condition 4 of malaria detection obtained a degree of belief of 92% for Malaria, 4% for Malaria, Gastroentritis, Lyme Disease and 3.3% for Malaria, Influenza, Gastroentritis, Lyme Disease. Condition 5 of malaria detection obtained a degree of belief of 97% for Malaria, 0.2% for Malaria, Gastroentritis, Lyme Disease and 2.7% for Malaria, Influenza, Gastroentritis, Lyme Disease. Condition 6 of malaria detection obtained a degree of belief of 98.6% for Malaria, 0.2% for Malaria, Gastroentritis, Lyme Disease and 1% for Malaria, Influenza, Gastroentritis, Lyme Disease. Finally, malaria detection using mathematical theory of evidence has shown good results.

References

Chidi, A.P., Chishimba, S., Kobayashi, T., Hamapumbu, H., Mharakurwa, S., Thuma, P.E., and Moss, W.J. 2011. Validation of oral fluid samples to monitor serological changes to Plasmodium falciparum: an observational study in southern Zambia. Malaria Journal. 10, 162.

Chitnis, N., Schapira, A., Smith, D.L., Smith, T., Hay, S.I., and Steketee, R.W. 2010. Mathematical modeling to support malaria control and elimination. Roll Back Malaria Progress and Impact Series, Number 5, Roll Back Malaria, Geneva, Switzerland, 48 p.

Dempster, A.P. 1967. Upper and lower probabilities induced by a multivalued mapping. Annals of Mathematical Statistics. 38, 325-339.

Dempster, A.P. 1968. A generalization of bayesian inference. Journal of the Royal Statistical Society. B(30), 205-247.

Estevez, P.T., Satoguina, J., Nwakanma, D.C., West, S., Conway, D.J., and Drakeley, C.J. 2011. Human saliva as a source of anti-malarial antibodies to examine population exposure to Plasmodium falciparum. Malaria Journal. 10, 104.

Fung, A.O., Damoiseaux, R., Grundeen, S., Panes, J.L., Horton, D.H., Judy, J.W., and Moore, T.B. 2012. Quantitative detection of PfHRP2 in saliva of malaria patients in the Philippines. Malaria Journal. 11, 175.

Han, E.T. 2013. Loop-mediated isothermal amplification test for the molecular diagnosis of malaria. Expert Review of Molecular Diagnostics. 13, 205-18.

Moonen, B., Cohen, J.M., Snow, R.W., Slutsker, L., Drakeley C., Smith, D.L., Abeyasinghe, R.R., Rodriguez, M.H., Maharaj, R., Tanner, M., and Targett, G. 2010. Operational strategies to achieve and maintain malaria elimination. Lancet. 376, 1592-1603

Najafabadi, G., Oormazdi, H., Akhlaghi, L., Meamar, A., Nateghpour, M., Farivar, L., and Razmjou, E. 2014. Detection of Plasmodium vivax and Plasmodium falciparum DNA in human saliva and urine: Loopmediated isothermal amplification for malaria diagnosis. Acta Tropica. 136, 44-49.

Nantavisai, K. 2014. Malaria detection using non-blood samples. Songklanakarin Journal of Science and Technology. 36(6), 633-641.

Pooe, O.J., Shonhai, A., and Mharakurwa, S. 2011. A PCR screen for malaria carrier infections using human saliva samples. African Journal of Microbiology Research. 5, 5120-5126.

Putaporntip, C., Buppan, P., and Jongwutiwes, S. 2011. Improved performance with saliva and urine as alternative DNA sources for malaria diagnosis by mitochondrial DNA-based PCR assays. Clinical Microbiology and Infection. 17, 1484-91.

Shafer, G. 1976. A Mathematical Theory of Evidence, Princeton University Press, New Jersey, U.S.A., 1976.

Singh, R., Savargaonkar, D., Bhatt, R., and Valecha, N. 2013. Rapid detection of Plasmodium vivaxin saliva and blood using loop mediated isothermal amplification (LAMP) assay. Journal of Infection. 67, 245-7.

Singh, R., Singh, D.P., Gupta, R., Savargaonkar, D., Singh, O.P., Nanda, N., Bhatt, R.M., and Valecha, N. 2014. Comparison of three PCR-based assays for the non-invasive diagnosis of malaria: detection of Plasmodiumparasites in blood and saliva. European Journal of Clinical Microbiology and Infectious Diseases.

Stuart, R. and Peter, N. 2002. Artificial intelligence: a modern approach. Beijing: Post and Telecommunications Press, China.

Tanner, M. and Hommel, M. 2010. Towards malaria elimination–a new thematic series. Malaria Journal. 9, 24.

Wang, Y .Q. 1998. Principles and methods of artificial intelligence. Xi'an: Xi'an Jiaotong University Press, China.

WHO, 2015. Malaria Fact Sheeto94. World Health Organization, Geneva, Switzerland

Yager, R. 1986. Arithmetic and other operations on Dempster-Shafer structures. International Journal of Man-Machine Studies. 25, 357-366.