International Journal of Medical, Medicine and Health Sciences
ISSN: 2517-9969
Vol:1, No:1, 2007

Towards Automatic Recognition and Grading of *Ganoderma* Infection Pattern Using Fuzzy Systems

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***Abstract*—** This paper deals with the extraction of information from the experts to automatically identify and recognize *Ganoderma* infection in oil palm stem using tomography images. Expert's knowledge are used as rules in a Fuzzy Inference Systems to classify each individual patterns observed in he tomography image. The classification is done by defining membership functions which assigned a set of three possible hypotheses : *Ganoderma* infection (G), non *Ganoderma* infection (N) or intact stem tissue (I) to every abnormalities pattern found in the tomography image. A complete comparison between Mamdani and Sugeno style,triangular, trapezoids and mixed triangular-trapezoids membership functions and different methods of aggregation and defuzzification is also presented and analyzed to select suitable Fuzzy Inference System methods to perform the above mentioned task. The results showed that seven out of 30 initial possible combination of available Fuzzy Inference methods in MATLAB Fuzzy Toolbox were observed giving result close to the experts estimation.

***Keywords*—** Fuzzy Inference Systems, Tomography analysis, Modelization of expert's information, *Ganoderma* Infection pattern recognition

I. Introduction to the Basal Stem Rot (BSR) diseases in oil palm

BASAL STEM ROT (BSR) diseases in oil palm is caused by the attack of a group of wood decaying fungi called *Ganoderma*. This fatal disease is considered as the most serious disease of oil palm in Malaysia [5], [4] where losses can reach up to 80% after repeated planting cycles.

Ganoderma produces enzymes that will degrade the oil palm tissue and affect the infected oil palm xylem thus causing serious problems to the distribution of water and other nutrients to the top of the palm tree.

A. *Ganoderma infection identification*

The basidiocarp is the most identifiable structure associated to the fungus. The conk originates from the fungus that grows in the infected trunk. However, most of the time, the conk do not appear at the early stage of the infection, making early detection of the disease very difficult.

The ability to perform an early detection of the infection will enable the palm to be treated at the early stage of the infection and thus avoiding more extensive damage on the palm.

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Until today, few methods based on biochemistry process were used to detect *Ganoderma* infection which can be divided into two categories; Culture based by using *Ganoderma* Selective Medium (GSM) or molecular DNA based such as a polymerase chain reaction (PCR) amplification [6]. These methods require the collection of stem samples from four angles of the palm for further test in the lab. There are no methods available which are able to give the result of the test directly on the site.

In this framework, we suggest a study to extract rules from expert's knowledge to identify the presence of *Ganoderma* fungus in the palm stem based on the recognition of the infection lesion in the stem using tomography image. These rules will enable us to perform automatic detection directly in the plantation.

This article presents the first steps to design and select proper method of fuzzy inference systems to detect *Ganoderma* infection as follows; section II is devoted to the presentation of the expert's current knowledge on *Ganoderma* infection pattern in the palm stem. The tomography images based on the sound propagation in the stem to detect abnormalities in the stem is presented in section .A general idea of Fuzzy Inference System to generate oil palm health condition using rules established with the help from the experts and the features extracted from the tomography images to assign the membership functions to a set of three possible hypotheses : *Ganoderma* infection (G), non *Ganoderma* infection (N) or intact stem tissue (I) for every abnormalities pattern found in the tomography image is proposed in section III. A complete comparison between Mamdani and Sugeno style,triangular, trapezoids and mixed triangular-trapezoids membership functions and different methods of aggregation and defuzzification is then presented in section IV to enable selection and decision of a final Fuzzy Inference System for the detection of *Ganoderma* infection in oil palm stem.

II. Identifying *Ganoderma* infection pattern in the oil palm stem

A. *Expert's knowledge on Ganoderma infection pattern*

According to Turner [11] and Idris et al., [14], *Ganoderma* infection can be well defined by its lesion in the stem. The cross section of infected palm stem shows that the lesion appears as a light brown area of rotting tissue with a distinctive irregularly shaped darker band at the borders of this area. [11] and Schwarze and Ferner [13] also noted that in very old lesion, the infected tissue may become as an ashen-grey powdery and if the palm remains standing, the infected trunk may become hollow. The position, number and condition of these lesions depend on the upwards evolution of the attack and the origins of the infection. As the *Ganoderma* attack location is often limited to the roots and the lower zone of the palm tree, a detection approach should focus on the stem area close to the ground.

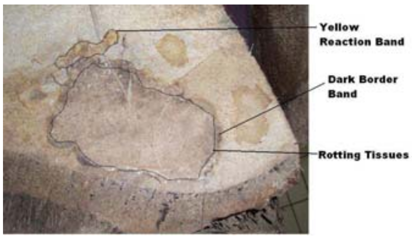

Fig. 1. *Ganoderma* infection lesion in a cross section of an oil palm stem

Figure 1 shows an example of the tomography of a cross section of an infected stem. Note that in this figure the lesion appears as a light brown area of rotting tissue with a distinctive irregularly shaped darker band at the borders of this area. A yellow reaction zone is also clearly identified. As the infection moves upwards from the roots, this zone can be first observed in a cross section prior to the appearance of the light brown infected area.

B. Characteristics of *Ganoderma* infection for automatic recognition

A non destructive approach which is able to explain explicitly *Ganoderma* infection in a readable way is then still blocked because (*i*) there are lack of knowledge on *Ganoderma* lesion pattern as the infection are hidden inside the stem and not many sample were available and studied prior to this work (*ii*) the characteristics of the infection symptoms can be confused with other kinds of less important infection

In this work, we propose to use a tomography image integrated in a quasi non destructive method for the detection. Our prototype is based on the extraction of reliable features from the tomography image that aer believe to be closely related to the presence of *Ganoderma* in the stem. The choice of these features are defined by studying with biologists various cases of degradation in the palm stem. Then, the use of rules to model the knowledge allows to have a convenient way to represent the complementarity between acquired physical data and experts' knowledge, in order to tune the set of rules, improving both the physical model and the knowledge.

Figure 2 shows an example of a Sonic Tomography image of a palm with a decay and degradation lesion due to *Ganoderma* infection. This image was selected as it contains both decay and degradation zone as well as the shape and position that represent *Ganoderma* infection in a palm tree. However, the decay and one of the degradation zone which are closer to the external area of the palm also reflect the possibility of other disease or insect attack in the tree.

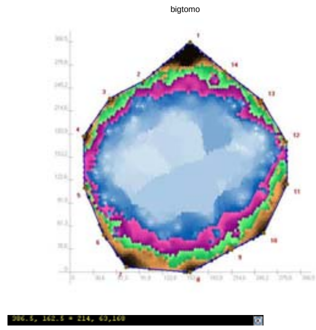

Fig. 2. A tomography image obtained from Sonic Tomography Detector

C. Image analysis

Because chromatic levels are used for coding the tomographic image, it is better to use a color space able to distinguish the three layers in luminosity and chromatic ones. The most used one is the CIE $L^*a^*b^*$, in which luminosity L^* (or brightness) layer is separated from both the first chromaticity layer a^* indicating where color falls along the red-green axis, and the second chromaticity layer b^*, indicating where the color falls along the blue-yellow axis ([3]). One of the main reasons to use this color space, whereas the RGB one, is that the difference between two colors in the $L^*a^*b^*$ space is identically perceived by a human's eye.

Consequently, the decay zone (blue), the degradation zone (violet) and the solid zone (brown) are easily detected. Then, for each zone i in the image, we calculate the average value $\widehat{a_i^*}$ of a_i^* and $\widehat{b_i^*}$ for b_i^*. In order to extract zone i with average value $\widehat{a_i^*}$ and $\widehat{b_i^*}$, we calculate the distance between all value 'a^*' and 'b^*' to the $\widehat{a_i^*}$ and $\widehat{b_i^*}$ for every pixel in the image.

Then all the pixels related with the minimum value of $(distance((a^*, \widehat{a_i^*}), ((b^*, \widehat{b_i^*}))$ belong to region i. Finally, each region is converted to binary pattern for further analysis. The Figure 3 presents the detection of one decay pattern and two degradation patterns from the cross-section scan show in the Figure 2.

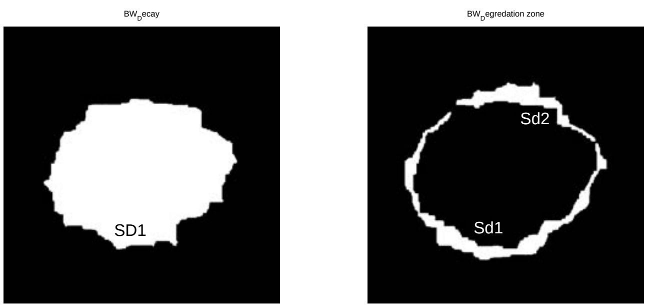

Fig. 3. Decay and degradation zone detected

In figure 3, we observed three different patterns, a decay $SD1$, and two degradation zone $Sd1$ and $Sd2$. Relevant features are extracted from the objects as the input to the proposed Fuzzy Inference System. According to the expert, Object $SD1$

is a possible decay caused by *Ganoderma* infection however due to the position of the area which is very close to the external section of the palm, the decay might also be caused by insects or other known palm disease. Object $Sd1$ is also having a shape that is normal to the light brown area of rotting tissue caused by *Ganoderma* infection, but again due to it's closeness to the external area, there is a small possibility that this degradation is caused by insects. The shape of object $Sd2$ is similar to the trace of chemical injection for palm treatment. However as the position of the object is not close to the external zone, the possibility of *Ganoderma* infection cannot be ignored.

D. Relevant features extraction

A series of possible infection lesion pattern were proposed to an expert for evaluation. The expert identified *Ganoderma* infection lesion pattern among the proposed lesion according to his knowledge and experience. Based on the expert's method to differentiate *Ganoderma* infection, the pattern can be divided into two categories; infection near the center of the stem and infection located on the external layer of the stem. The chance of detecting a decay or degradation caused by *Ganoderma*, the main purpose of this study, is higher if the decay or degradation is identified by Sonic Tomography at the center of the cross section under study. By the contrary, decay or degradation area detected at the external zone can be due to a previous chemical injection[1]or caused by insect attack. The expert is also using the lesion shape and orientation to differentiate *Ganoderma* infection from other infection.

The following features were identified to be used by the expert to recognize lesion with *Ganoderma* infection.

1) Infection pattern 's Eccentricity;
2) Infection pattern 's Orientation;
3) Infection pattern 's Solidity;
4) Infection pattern 's Roundness;
5) Infection pattern 's Area and size
6) Infection pattern 's Position in the cross section;

These features together with the color of the pattern in the tomography image which differentiate the decay and degradation pattern were used to establish an Expert's rules used in a 8 input 3 output Fuzzy Inference Systems to classify the pattern in three classes *Ganoderma* degradation, non *Ganoderma* degradation and intact. According to the pattern features (Type(Decay/Degradation), Eccentricity, Orientation, Solidity, Roundness, Position in the cross section, Area and size), the degree of possibility (zero, low, average and high) of the pattern to belong to one of the above mentioned class are proposed as the output of the Fuzzy Inference Systems. Note that this is the first attempt to extract expert's knowledge in terms of rules.

III. Fuzzy Inference System for *Ganoderma* Infection Pattern Classification

Negevitsky [8] mentioned that fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The decision level is made based on the mapping. There are four primary elements in the fuzzy inference system, namely, fuzzy sets, membership function, fuzzy logic operators and production rules. Fuzzy Sets and Fuzzy Inference were applied to identified or classify objects as in [9],[1],[2].

Most commonly used fuzzy inference technique are Mamdani style and Sugeno style. The FIS rule base for Mamdani style is made of rules in the following form:

- IF object's eccentricity,e is circle
- AND the position of the object,$p$is close to the center of the cross section
- THEN G is High

For Sugeno style, the rules is of the following form:

- IF object's eccentricity,e is circle
- AND the position of the object,$p$is close to the center of the cross section
- THEN G is f(e,p)

f(e,p) is a mathematical fuction

Most commonly used Sugeno fuzzy model applies rules with $f(e,p) = k$. Where k is a constant.

The inference is performed in four steps; fuzzification of the input variable, production rule evaluation, aggregation of the rule outputs and defuzzification.

Fuzzification is the step to determine the membership degree to which the inputs belong to the appropriate fuzzy set. This fuzzified inputs are then applied to the antecedents of the fuzzy production rules. Fuzzy operators AND and OR are used for multiplying antecedents rules. This will enable us to obtain a single number that represent the result of antecedents evaluation. This number is then applied to the consequent membership function.

The disjunction ($\bigcup$) of the rule antecedents is handled by using the OR fuzzy operation. Two most commonly used OR method are; fuzzy OR (MAX)(see equation 1) and probabilistic OR (see equation 2)[8].

$$\mu_{A \bigcup B}(x) = max\{\mu_A(x), \mu_B(x)\} \tag{1}$$

$$\mu_{A \bigcup B}(x) = \mu_A(x) + \mu_B(x) - \mu_A(x) * \mu_B(x) \tag{2}$$

AND fuzzy operation are used to evaluate the conjunction ($\bigcap$) of the rule antecedents. Two most commonly used AND fuzzy operation methods are; fuzzy AND (MIN)(see equation 3) and product AND (see equation 4)[8].

$$\mu_{A \bigcap B}(x) = min\{\mu_A(x), \mu_B(x)\} \tag{3}$$

$$\mu_{A \bigcap B}(x) = \mu_A(x) * \mu_B(x) \tag{4}$$

Several methods to perform aggregation and defuzzification are available in the MATLAB Fuzzy Logic Toolbox.

[1]Biologists drill a hollow to inject chemical treatment

A. Our Approach

In this work, the initial FIS was design using Mamdani style as in [12] using fuzzy AND MIN and OR MAX operators with a triangular membership function. SUM method is used for the aggregation stage and centroid defuzzification is applied at the defuzzification stage. Later in the comparison paragraph, the performance of this system is compared with other system using different type of membership function (Trapezoids and Combination of Trapezoids and Triangular),operators (probabilistic OR, product AND), aggregation method (MAX, SUM, PROBOR) and defuzzification technique (Centroid and Bisector)[10]. We also compared the performance of the system with the performance using FIS with Sugeno style [7] with different defuzzification methods (wtaver,wtsum).

Due to the limited available knowledge on *Ganoderma* infection pattern, we have decided to use only the rules established with the help form the expert to initiate the proposed Fuzzy Inference System. New rules will be added once the filed testing is conducted.

Example of membership function used in this work is presented in Figure 4, Figure 5, Figure 6 and Figure 7.

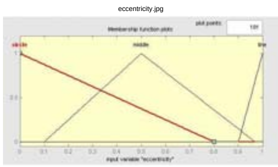

Fig. 4. Example of Triangular Membership Function for Eccentricity

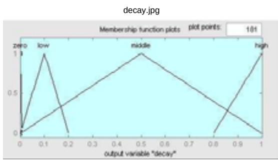

Fig. 5. Example of Triangular Membership Function for Decay/Degradation due to *Ganoderma* Infection

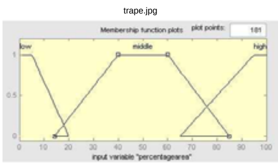

Fig. 6. Example of Trapezoids Membership Function

Eccentricity input uses three membership function; circle, middle and line to differentiate the infection patterns which are normally close to a circle from the effect due to chemical injection which is normally having a pencil shape lesion.

Three membership functions are also used for the closeness inputs which are close to center, middle and external. The position of the pattern is analyzed as a lesion found at the center of the stem is more likely to be caused by *Ganoderma* infection while the one near to the external area can be due to chemical injection or insect attack.

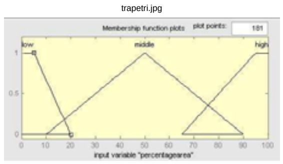

Fig. 7. Example of Mixed Triangular-Trapezoids Membership Function

TABLE I
INFECTION GRADING FOR THE EXAMPLE TOMOGRAPHY IMAGE

Object	*Ganoderma*(G) infection	non *Ganoderma*(N) infection	intact (I)
S_{D_1}	0.93667	0.62949	0.079563
S_{d_1}	0.93667	0.59687	0.071635
S_{d_2}	0.93667	0.93667	0

The orientation input is having 5 membership functions which are, -90^0,-45^0,0^0,
45^0, 90^0. The orientation allows differentiation of chemical injection from the infection. Chemical products were introduced inside the stem with a regular angle while the orientation of an infection pattern is not regular.

We used three membership functions for percentage area input to measure the severeness of the attack.

For number of point at boarder input, two membership functions are used; not many and many. Small number of point at border reflect the possibility of having a lesion caused by insect attack or chemical injection.

Roundness input is having three membership functions; line, ellipse and circle. This is also used to differentiate the irregular *Ganoderma*infection pattern from regular pattern.

Three membership functions are used for solidity input;low, middle,high. This input provides information on the shape of the pattern. A solid shape indicates a circle,oval, pencil trace or other regular shape while low solidity indicates an irregular pattern.

Three outputs were proposed in the system, *Ganoderma* infection, non *Ganoderma* infection and intact. All the three inputs were assigned with four membership functions, zero, low,middle and high.

Applying the Fuzzy Inference System to the selected tomography, we obtained the following output result on the membership degrees for the three output G,N and I as shown in table I.

Normalizing the result obtained in I, we obtained the following result in table II.

In this particular example, the system suggest that there are 57% of chances that the lesion numbered $SD1$ is caused by *Ganoderma* infection,38.2% possibility that this lesion is caused by other disease and 4.8% that the lesion appeared in the tomography image is actually an intact stem. The same observation can also be done for lesion $Sd1$ and $Sd2$ as indicated in the table II.

TABLE II
INFECTION GRADING FOR THE EXAMPLE TOMOGRAPHY IMAGE AFTER NORMALIZATION

Object	*Ganoderma* infection(%)	non *Ganoderma* infection(%)	intact (%)
S_{D_1}	0.570	0.382	0.048
S_{d_1}	0.583	0.372	0.045
S_{d_2}	0.5	0.5	0

IV. COMPARATIVE STUDY BETWEEN SEVERAL FUZZY INFERENCE SYSTEMS METHODS

We have tested 30 different Fuzzy Inference Systems with different membership function, operator,aggregation and defuzzification methods in this work. Results from our experiments shows that the defuzzification using mom (middle of maximum), som (smallest of maximum), lom (largest of maximum) for Mamdani-style inference and wtsum (weighted sum) for Sugeno-style inference failed to give distinctive values between output classes (G,N and I).

The result obtained to grade the believe that $SD1$ is a *Ganoderma* infection, non *Ganoderma* infection or an intact lesion using different fuzzy inference methods are presented in figure 8

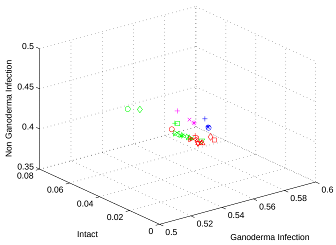

Fig. 8. Comparison between several Fuzzy Inference Methodology for $D1$

We observed that results obtained using Sugeno style inference and some of Mamdani Style with Probabilistic OR and Product AND gave higher value for the possibility of having $SD1$ as non *Ganoderma* infection.

The result obtained to grade the believe that $Sd1$ is a *Ganoderma* infection, non *Ganoderma* infection or an intact stem using different fuzzy inference method are presented in figure 9

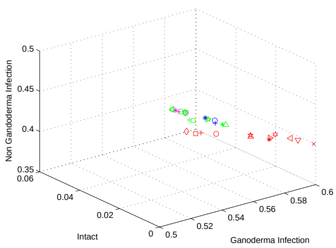

Fig. 9. Comparison between several Fuzzy Inference Methodology for $d1$

We observed that results obtained using Sugeno style inference and Mamdani Style with Probabilistic OR and Product AND gave high value for the possibility of having $Sd1$ as non *Ganoderma* infection and as Intact.

The result obtained to grade the believe that $Sd2$ is a *Ganoderma* infection, non *Ganoderma* infection or an intact stem using different fuzzy inference method are presented in figure 10

TABLE III
BIOLOGIST ESTIMATION

Object	$\widehat{Ganoderma}$ infection(%)	$\widehat{nonGanoderma}$ infection(%)	$\widehat{intact}(\%)$
S_{D_1}	0.8	0.2	0
S_{d_1}	0.85	0.3	0
S_{d_2}	0.85	0.3	0

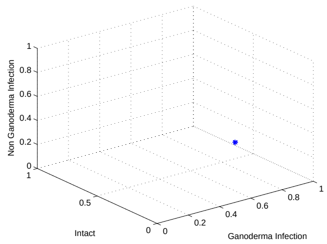

Fig. 10. Comparison between several Fuzzy Inference Methodology for $d2$

We obtained a same result from all different method tested.

We have asked the expert to estimate the percentage of his believe on the *Ganoderma* infection (G), non *Ganoderma* infection (N) or an intact (I) stem for the lesion $SD1$,$Sd1$ and $Sd2$ found in the tomography image. The result is presented in table III.

To avoid over grading of believe on the *Ganoderma* infection due to the lack of experience of the biologist in interpreting the tomography, we have to further analyze the biologist estimation of $\widehat{G}SD1$,$\widehat{G}Sd1$ and $\widehat{G}Sd2$, $\widehat{N}SD1$,$\widehat{N}Sd1$ and $\widehat{N}Sd2$ and $\widehat{I}SD1$,$\widehat{I}Sd1$ and $\widehat{I}Sd2$ in giving the believe level for the three classes G,N and I. In this point of view, the difference between classes, for example $\widehat{G}SD1$ - $\widehat{G}Sd1$,$\widehat{G}SD1$ - $\widehat{G}Sd2$, $\widehat{G}SD1$ - $\widehat{NG}SD1$,... are calculated. These values are then referred as Biologist values. The same difference between classes of table II is also calculated and referred to as Fuzzy Inference value. The same calculation was also performed on all results from all different fuzzy inference methods.

We than calculate the Euclidean distance between Biologist values and the Fuzzy Inference value and obtained the following result in figure 11

We found that the result obtained from Mamdani style inference with Fuzzy AND and Fuzzy OR gives a closer values to the expert's estimation as compared to the Probabilistic OR and Product AND and from any Sugeno style fuzzy inference system. The closest result is obtained with Trapezoid Membership Function, MAX Aggregation and Bisector Defuzzification.

Due to the lack of available data in this initial step, we have tested the procedure in six different available tomographies with each tomography containing specific *Ganoderma*

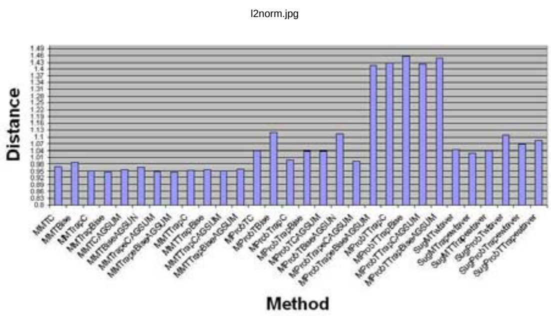

Fig. 11. Distance to Expert's estimation

infection pattern. The closest distance were observed while using the following methods:

1) Mamdani type, AND Fuzzy and OR, Triangular Membership Function, MAX Aggregation and Centroid Defuzzification
2) Mamdani type, AND Fuzzy and OR, Triangular Membership Function,MAX Aggregation and Bisector Defuzzification
3) Mamdani type, AND Fuzzy and OR, Triangular Membership Function,SUM Aggregation and Bisector Defuzzification
4) Mamdani type, AND Fuzzy and OR, Triangular Membership Function,SUM Aggregation and Centroid Defuzzification
5) Mamdani type, AND Fuzzy and OR, Trapezoid Membership Function,MAX Aggregation and Bisector Defuzzification
6) Mamdani type, AND Fuzzy and OR, Trapezoid Membership Function,SUM Aggregation and Centroid Defuzzification
7) Mamdani type, AND Fuzzy and OR, Trapezoid Membership Function,SUM Aggregation and Bisector Defuzzification

V. Conclusion

In this paper we showed the possibility to develop an automatic detection of *Ganoderma* infection in oil palm stem using the Sonic Tomography image and a fuzzy inference system. Practically, a method to extract *Ganoderma* infection rules based on selected features is introduced. The features are observed and extracted from a segmented tomography images. The rules are designed based on *Ganoderma* infection expert's knowledge on the infection patterns in the oil palm stem, modelized within the Fuzzy Inference System model as membership function.

The rules used in the fuzzy inference system introduced in this work were purely based on experts' experience and knowledge on *Ganoderma* infection, the fuzzy rules are a convenient representation of the biologist's understanding of the phenomenon. However, such a model suffers from the variability of the points of view given by each expert. This can imply possible incoherencies : the main role of the fuzzy inference is to make appear a generalized set of infection grading. Some real data testing will be conducted in future to verify and improve the rules.

We also compared results obtained by using different Fuzzy Inference methods using MATLAB Fuzzy Logic Toolbox. The results showed that seven out of 30 initial possible combination of available Fuzzy Inference methods in MATLAB Fuzzy Toolbox were observed giving result close to the experts estimation. We have suggested that the final Fuzzy Inference Systems chosen to perform in our system will use one of the seven methods. A further study will be conducted when we will conduct our field testing. We also plan to include hedges such as very high and very low as the output membership function to reduce the distance between Fuzzy Inference results and Expert's estimation. New rules will be added and result of the seven methods will be compared to select the best method that give consistently the closest result to the expectation of the experts.

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