Optimizing the Telemedicine Services and Health Informatics From System Identification of the Risk Level in Peruvian Northwestern Cities.

Huber Nieto-Chaupis
Universidad de Ciencias y Humanidades
Center of Research eHealth
Av. Universitaria 5175, Los Olivos, Lima 39, Peru
Email: huber.nieto@gmail.com

***Abstract*—We use the so-called nonlinear system identification methodology to model the level of risk in those Peruvian Peri urban zones along the northwestern cities and which are under an imminent thread of being flooded due to climate changes. In this paper we evaluate the prospective role of the eHealth services which might be relevant in the sense of providing effective assistance in times of flooding particularly in those vulnerable human groups. To this end we use a mathematical formalism that identifies the system to extract the main system parameters of the system for a subsequent usage of them in the modeling of Telemedicine services and eHealth dynamics. We present some simulations of how these electronic services can be useful to attenuate critic consequences. This paper evaluates the fact of deploying ehealth services in areas of risk in the city of Piura.**

I. Introduction

A. Motivation

Commonly northwestern cities have been subject of drastic climatic changes concretely in times of the arrival of ”El Niño Costero” where the aftermaths by flooding has been an issue of a supreme importance due to the potential human groups to be affected particularly along the Peri-Urban areas of the large cities. Concretely, this study is based on the prospective usage of the ehealth services on that groups of risk which are very sensitive to acquire diseases as product of flooding in summer times. In fact, with the experiences of the 2017 summer various districts located along the Peruvian North Coast were affected by severe floods and rains affecting mostly Peri-urban areas and near to rivers, essentially. Clearly, it has huge effect on those vulnerable population whose imminent risk can be anticipated by using methods of the applied mathematics, engineering and telemedicine.

B. What’s Done in this Paper?

We can summarize the contribution of this paper as follows:

- We set a mathematical model,
- We apply such model to a geographical area under risk,
- We identified such Peri-urban areas,
- We perform simulation to assess the role of eHealth services in flooding times.

Essentially we used the nonlinear convolution formalism those that due to their intrinsic nature of being nonlinear most of them can emulate a fully and stochastic system to some extent. Normally one can use the well-know Wiener and Volterra series since both are characterized by having a well-defined input and output, fact that adjust well to describe under certain approximations a nonlinear system. Special attention is paid on the Volterra series since it have been used for the understanding of how those linear and nonlinear systems are evolving in time together with others variables which might be of importance to get a wide vision of systems under studies [1-4]. Although the application of this formalism is quite promising, normally the Volterra’s algorithms would involve excessive time consumption because the presence of a huge number of kernels. Roughly speaking the full series can be written as

$$y(t) = \int ... \int h(\tau_1, ..., \tau_n) \prod_{j=1}^{n} x(t-\tau_j) d\tau_j \tag{1}$$

The right side of (1) shows the complex characteristic of these infinite expansion that contributes to the full output $y(t)$ and the presence also of a huge or infinite numbers of kernels, which are describing the system properties. In our case the output is seen as the risk of a certain Peri-urban area located to a certain distance of a overflowed river. Thus once the distances have been extracted we can assess the prospective role of a Tele-consultation system just near to the identifies zones of risk. Thus when the distances are identified we can write down that the efficiency of the deployment of the eHealth systems as function of these identified distances just for those critic times of the arrival of flooding, etc,

$$\mathrm{Eff} = \mathrm{E}[y(t)] \tag{2}$$

Thus for the sake of the simplicity and as done in most cases accoding to the literature, such series can be truncated in those orders by which the system can be described approximately. In other cases, the system need to be identified accurately and therefore the knowledge of the Volterra’s kernels with high precision is a must because the presence of instabilities and random fluctuations, so the tunning of the kernel’s values should be quite fine by minimizing the errors attained to the numerical and computational methods [5-12].

Digital Object Identifier (DOI): http://dx.doi.org/10.18687/LACCEI2018.1.1.395
ISBN: 978-0-9993443-1-6
ISSN: 2414-6390

II. The Mathematical Machinery

A. Series of Convolutions: The Volterra Series

The well-know Volterra series, is commonly used in system identification and control theory as reported by the literature [1][2]. Most of them were used in the study of those nonlinear systems containing more than one variable, being of type MIMO [3] for example. The Volterra series can be established as one method of precise identification of variables evolving in time. Mainly, one has as main task for an efficient usage of the model the extraction of the kernels which are required with most precision for cases of control systems [4][5]. Clearly among the most troublesome features of the Volterra method, becomes the precise calculation of the kernels. Therefore numerical approaches and computational methodologies were used. To illustrate the mentioned above the second-order truncated Volterra model can explicitly written as

$$y(t) = y_0 + \int h(\tau_1)x(t-\tau_1)d\tau_1 + \int\int h(\tau_1)h(\tau_2)x(t-\tau_1)x(t-\tau_2)d\tau_1 d\tau_2 \tag{3}$$

where $h(t,\tau_1)$ and $h(t,\tau_2)$ denote the kernels, and $x(\tau_1)$ and $x(\tau_2)$ the input functions. Integrations are performed over the all values of τ_1 and τ_2. The quantity y_0 becomes the initial error of the measurement of the output in $t=t_0$. In most cases this value is unknown but normally it is extracted from data accurately. In "fast" systems, the input functions might be for instance the well-known Delta functions namely $\delta(\tau_1)$ which would denote a type of initial impulse applied to the system. In "slow" systems, input functions might be represented by continuous functions (e.g. higher order polynomials, etc). Due to the stochastic nature of the faced problem in this paper, an interesting scenario for testing the second order truncated Volterra series, are the cases where the input functions are interpreted as stochastic representations or probabilistic distributions. In these cases these functions are presenting peaked distributions and some parameters are needed to be defined. In order to provide a single and weighted representation containing all of them, we propose the following input function which is written as a delayed function because the formulation of the Volterra series as seen in Eq.3. So that we adjudicate a probabilitic meaning to the input and output of the Volterra series,

$$\mathcal{P}(t-\tau) = p_0 \sum_{q=1,3}^{L} \left[\mu_q \mathcal{P}_q(t-\tau)\right] \tag{4}$$

where $q = 1, N$ specifies the number of classes of stochastic input functions as written above and having the stochastic interpretation. The parameters μ_q have as role the normalization of the individual input function together to the quantity p_0. The parameter μ_q also absorbs the numerical weighting for each one of the stochastic functions. Once the inputs are defined then the kernels. Normally, the Volterra series in the discrete case faces the problem for handling and solving the kernels, precisely. It's done by using computing and algorithms which would yield acceptable values for the output functions within certain errors [6][7][8]. In the other side, a method which has been also widely used is that of the estimation of the kernels with the expansion onto orthogonal functions [9]. It is seen as follows: given a kernel $h(t,\tau)$ then a possible representation of that is expressed in terms of an infinite expansion as $\sum_{j=1}^{N} c_j(t)\phi_j(t,\tau)$ where exists there a sum over the product of coefficients times polynomials belonging to a type of orthogonal or similar. So that the main task from the computational angle is that of extracting the kernels with a substantial precision.

B. The Full Output Function for the 2th Order

The resulting output for a second order truncated Volterra series is written as

$$y(t) = y_0 + \int_0^{T_1} \sum_{j=1}^{N} c_j(t)\phi_j(t,\tau_1)\mathcal{P}(t-\tau_1)d\tau_1 + \int_0^{T_1}\int_0^{T_2} \sum_{j=1}^{N}\sum_{k=1}^{M} c_j(t)c_k(t)\phi_j(t,\tau_1)\phi_k(t,\tau_2) \times \times \mathcal{P}(t-\tau_1)\mathcal{P}(t-\tau_2)d\tau_1 d\tau_2, \tag{5}$$

and under the assumption that $\phi_j(t,\tau) \to \phi_j(\tau)\mathrm{Exp}(-\beta t)$ which means that the corresponding differential equation associated to $\phi_j(t,\tau)$ has the form $\triangle\phi_j(t,\tau) + \frac{d}{dt}\phi_j(t,\tau) = 0$. Clearly, the method of variable separation can help us to find the possible solutions by equaling $\frac{d}{dt}\phi_j(t,\tau) = -\beta$ which is equivalent to $\frac{1}{T(t)}\frac{d}{dt}T(t) = -\beta$. In addition, in the present case, we shall use orthogonal polynomials $\mathcal{P}_j(\tau)$ replacing the $\phi_j(t)$ functions. Now we go through the inputs functions which are written for the Gaussian case $\mathcal{X}(t-\tau) = p_A \mathrm{Exp}(-\frac{t-\tau_1}{\gamma^2})^2$. Here, we assume that the parameter p_A is known from measurements. The constant γ would describe to some extent the form of the input function but it would evolve in time getting low values and being neglected in large times (under the assumption that the system is depending of time) [9][10][11][12]. Clearly, the usage of these Gaussian profiles comes from the fact that these input functions are perceived as the probability which is after convoluted by the nonlinear characteristics of system. So that the complete output is taken here as the risk probability $\mathcal{R}(t)$ then can be written as

$$\mathcal{R}(t) = \int_0^{T_1} \sum_{j=1}^{N} c_j \mathcal{P}_j(\tau_1)\mathrm{Exp}(-\beta_j t)\mathcal{X}(\tau)d\tau_1 + \int_0^{T_1}\int_0^{T_2} \sum_{j=1}^{N}\sum_{k=1}^{M} c_j c_k \mathcal{P}_j(\tau_1)\mathcal{P}_k(\tau_2)\mathrm{Exp}\left[-(\beta_j+\beta_k)t\right] \times \times \mathcal{X}(t-\tau)\mathcal{X}(t-\tau)d\tau_1 d\tau_2, \tag{6}$$

Next task is the identification of the coefficients c_j and $c_j c_k = c_{j,k}$ which were set to be constants in time. We assume that the model is diagonal .

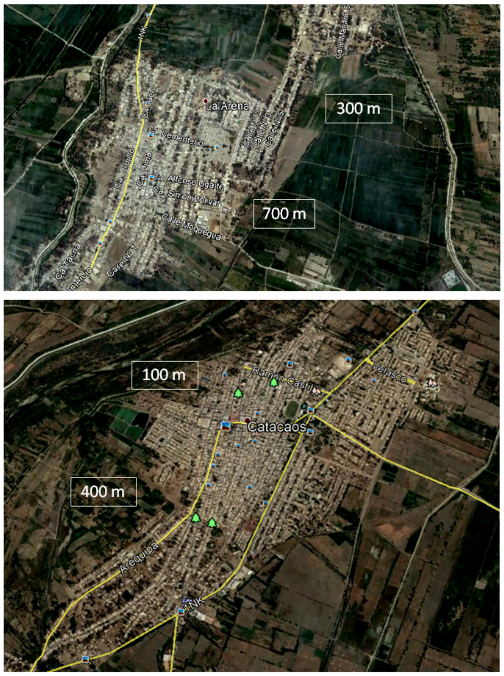

Fig. 1. Top and Bottom panels: areas in the city of Piura which are located near to the Piura river as seen at the indicated distances. Satellite images taken from Google-Earth.

III. The Risk Level from Truncated Volterra Model

A. Usage of Eq. 6

We now apply the resulting Eq. (6) to the concrete case of evaluation of the risk's level due to flooding in the city of Piura. Fig. 1, displays the case where districts appear to be adjacent to the Piura's river. In the top figure, we can see the district of "La Arena" whose Peri-urban area is located to 300 and 700m with respect to the Piura's river. So we can define a first relevant variable namely distance between river and Peri-urban locations. In down figure, the case of the district of "Catacaos" is seen. We can see that the distances are in the order of 100 and 400m. In both cases, clearly, there is a large probability of being flooded in summer times, just how it happened summer months of 2017. In order to evaluate the proposed model, we need to define the input function as one which is governed by Gaussian profiles more than the step function. The weight assigned to the function had turned to be small in compared with the Gaussian and step functions. Since $N = M = 3$, only Legendre functions up to third order were used. We have assigned to the range of integrations the values of $T_1 = 20$ and $T_2 = 25$ that are time units. For this example of application, the resulting output is interpreted as the probability of risk as function of time. Thus, we add further meaning to the other parameters mainly to the exponential ones, with the parameters β_j which are depending on the time: these functions denote the fall of the risk's level. On the other hand, the variable "distance between river and Peri-

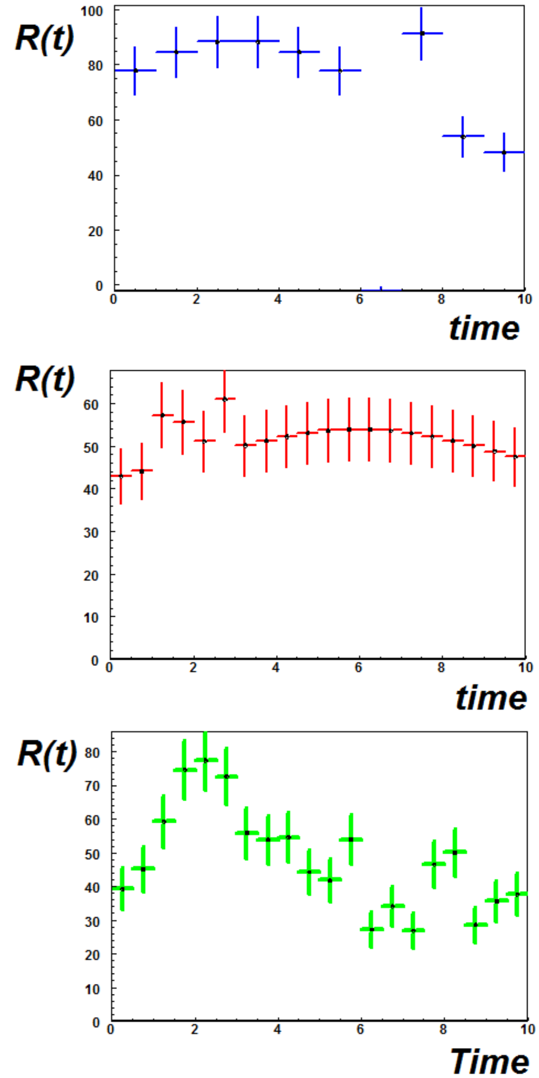

Fig. 2. Risk probability obtained with Eq. 5: the resulting integrations of the truncated Volterra series as function of days of flooding.

urban areas" is given by $\gamma_{j,[1,2]}$ which is correlated to the form of the Gaussian in time. Therefore c_j and c_k can be estimated from the next algorithm:

- The distances of flooding are calculated form pictures (bottom Fig. 2);
- We assign for each distance a probability corresponding risk's level;
- We build the input function: distribution of distances
- kernels acquire random variables
- If $\mathcal{R}(t)$ ¿ random, then $t_i \rightarrow t_{i+1}$.
- Under this step the kernels are extracted.

The computational estimation has required up to $i = 200$ with a partition of order of 0.05. One can see that this calculation is applied in the situations were flooding has started or arrived. Thus, the probabilities of risk have as essential role the identification of those areas under thread near to the Piura river. On the other hand, this procedure allows us to extract

TABLE I

BEST VALUES OF VOLTERRA'S COEFFICIENTS AND THEIR PROBABILITIES $\mathcal{R}(t)$ WITH DISTANCES ASSOCIATED.

Coefficient	0.9/50m	0.8/100m	0.5/300m	0.3/200m	0.1/100m
c_1	0.11	0.18	0.23	0.20	0.6
c_2	-0.01	0.05	0.11	0.01	1.4
c_3	1.7	0.92	-0.03	-0.06	0.04
$c_{1,1}$	-0.6	-0.5	-0.1	-0.5	0.7
$c_{2,2}$	0.04	-1.3	1.45	1.3	0.1
$c_{3,3}$	0.01	-1.7	0.28	-1.1	0.4

the Volterra coefficients as follows $c_1 = 0.23, c_2 = 0.11, c_3 = -0.03, c_{11} = -0.1, c_{22} = 1.45$, and $c_{33} = 0.28$. As mentioned previously, all these coefficients are kept to be constant along the time where the flooding is occurring in the Peri-urban areas. In figure 2, is showing up to three different curves of probability of Risk. These curves have been obtained with the values as listed in Table I. However this probability decreases with respect to the days. We can see that there up to 4 days where flooding overtakes the Peri-urban area located near to Piura river. The curve in Top denotes the probability for a distance of 200 m. Middle plot is the result for a distance of 500m. According to the application of the Volterra model, the area with more chance to be affected up to 5 days after the flooding has begun. Bottom curve is the case of 400 m. It indicates that the risk's level is above 80% during the 2th day. Although this method seems to be robust. However, the Volterra's coefficients are not enough stable to draw a well defined path of the probability. In other words, the Volterra model might not be accurate to describe the correlation of events in time. It is an interesting result, since both districts ("Catacaos" and "La Arena") are in praxis affected by the same event, and the possible coexistence of two different events of certain system in a single formulation might be beyond the scope of the Volterra model.

IV. TESTING A HEALTH INFORMATICS MODEL

By knowing the places that might be very sensitive to flooding, we pass to assess the impact of the implementation of an eHealth system. So we follow the following policy

- The distances to be affected with a high risk are estimated.
- We assign a list of health specialists to be available during the time of flooding ;
- We assign a random number of people to be attended by the eHealth service ;
- We define a success probability if the number of attendances was covered by the health specialists ;
- For a time given are random the number of requests and health personal.
- The probability of success is determined by hour.

A. The Success Probability

Consider the most trivial probabilities either success P_S or fail P_F of one single event by which is satisfied that P_S + P_F = 1. Then P_S = 1 - P_F, where the P_F can be understood as the probability where a single teleconsult fails with the respect to a fast and effective attention to only a person. **In epochs of high demand**, one expects that $P_F \to 0$. We assume that the teleconsult is done during the aftermaths of the flooding. Under this view, is possible to express the following: Let the product of a chain of probabilities of fail of teleconsults for successive times. Therefore the fail probability is a join probability in the sense that $P_{F,\mathrm{t}}$ = P_{F,t_1} $\times$ P_{F,t_2} $\times$ ... $\times$ $P_{F,\mathrm{t}_{\ell-1}}$ $\times$ P_{F,t_ℓ}, for ℓ teleconsults, as well as $P_{F,\mathrm{w}}$ = P_{F,w_1} $\times$ P_{F,w_2} $\times$ ... $\times$ $P_{F,\mathrm{w}_{\mathrm{q}-1}}$ $\times$ $P_{F,\mathrm{w}_\mathrm{q}}$, where $P_{\mathrm{F,W_q}}$ the probability of fails of the teleconsult for a worsening level W and for "q" persons.

Then we can write by assuming continuous variables, and taking into account an extra variable γ that measures the capacity of the eHealth services, thus $P_S(\gamma) = 1 - \beta_1 \int_{x_n}^{x_m} P_{\mathrm{F}}(x,\gamma) \otimes P_{\mathrm{W}}(x,\gamma) \otimes \rho_1(x) dx$. For example, P_S=1$-$ β $P_{F,}$ $\otimes$ $P_{F,}$ with β a random parameter. Then the fail of a teleconsult when probabilities are depending upon a continue variable x then this full fail is the convolution and written as an integration over the variable x: $P_{F,1}$=$\int$ $P_{F,}(x) \times P_{F,}(x) dx$ and the respective probability of success under this approach can be written as $P_S(\gamma)$=1-$\int$ $P_{F,\mathrm{t}_1}(x,\gamma)$ $\times$ $P_{F,\mathrm{w}_1}(x,\gamma) dx$. Therefore the the probability of success P_S for a single teleconsult can be explicitly written as

$$P_S(\gamma) = 1 - \beta_1 \int_{x_n}^{x_m} P_{\mathrm{T}}(x,\gamma) \otimes P_{\mathrm{WT}}(x,\gamma) \otimes \rho_1(x) dx, \quad (7)$$

where $\rho(x)$ is a continue function that accompanies the variable β_r and it is >0 inside the range between x_m and x_n.

Algorithm 1: Generates Random Attentions

Initialization
Assign initial values to β_j parameters
Initial bin x_0
repeat for $q \subset$ [0,100] cases P_F and ρ (Gaussian)
`Assign gender, age and weight`
  for $n \to 1$ **to** $\mathcal{N}$-bin **do**
  $x_n = x_n + x_{n-1}$
  Preparate $\mathrm{P}_s[x_n, \beta^q_{n,j}]$
    for $j \to 1$ **to** 5 **do**
      Define $c^q_{n,j}$ and $\theta^q_{n,j}$
        for $\ell \to$ (MC-steps) **do**
          if $c^q_{n,j} > \theta^q_{n,j}$ **then**
          $\beta^q_{n,j} \to \beta^q_{n,j} + \delta\beta^q_{n,j}$
            if $\ell \to \ell_{\mathrm{MAX}}$ **then**
            Calculate Monte Carlo averages
            Calculate errors
            end if
          end if
        end for
      end for
    end for
until q=100

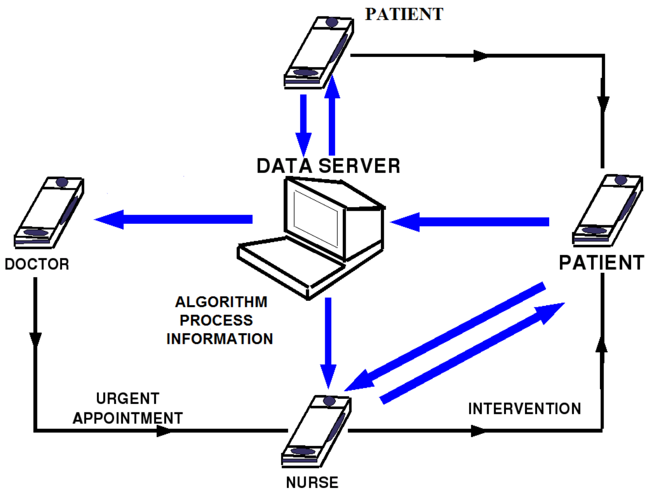

Fig. 3. Sketch of the proposed scheme in this work: Given a time $t = T_h$, people in zones of flooding send information to health personel to let to know them their current state. Information is stored to carry out calls and program attention in health center. The center therefore measures the arrival of people in according to the availability of doctors, etc.

Algorithm 2: Performs Tele-Consult

Initialization
Confirm information of L people
Confirm $\mathcal{N}$ available health specialists
repeat for T_h with $h = 1$
  $\mathbf{P}_S$PA=[$\mathbf{p}_{t_{k-s},l}, \mathbf{p}_{t_{k-s+1},l}, \ldots, \mathbf{p}_{t_{k-1},l}$]
  Present $\mathbf{P}_{\mathrm{S}}$=[$\mathbf{p}_{t_k,l}$]
  Defines $P_s = P_S$ ($\mathbf{P}_{\mathrm{P}}$,$\mathbf{P}_{\mathrm{P}}$)
    for r **to** R **do**
      $\mathcal{P}_S = \mathcal{P}_s + \mathcal{P}_S$
        if $r = \mathcal{P}$ **then**
        Finds max and min values or risk Eq.6
          if $\mathbf{P}^{l_J}_{t_{k+u}}$=$\mathbf{P}^{l_{\mathrm{MAX}}}_{t_{k+u}}$ **then**
          end if
        end if
      end for
      Assign value $\rightarrow \Gamma_l$ per Tele-Consult:
      for l_{MAX} **to** l_{MIN} **do**
        for p **to** $\mathcal{P}$ **do** selected ones
          if $\Gamma_l > \Gamma_{l,\mathrm{MIN}}$ **then**
            $\mathbf{P}^{l_J}_{t_{k+u}}$ `count teleconsult done`
            `print time and` P_S `per person`
            otherwise $\mathbf{P}^{l_J}_{t_{k+u}} \rightarrow p + 1$
            continue until $p + 1 \rightarrow \mathcal{P}$
          end if
        end for
      end for
until $h = h_{\mathrm{MAX}}$

V. Assessment of Tele-Consults and Results

A. Tele-Consult Algorithm

The functionality of a single or various teleconsults scheme depends in three basic points: (i) patients starts communication with nurse for

- inform update situation
- programs one attention

thus and following the policy of a teleconsultation as described in [16] the patient in addition sends updated information of their health status through a manager data by using a simple text message, (ii) the manager data runs a software based on a algorithm to estimate and evaluate the state of health in order to compute the list of priorities, and (iii) starting from the level of priority for all registered cases, a tele-consult is performed. The central idea of the tele-consult dynamics is sketched in Fig. 3. Where for the aftermaths times $j + N$ patients decide to send a text message to the receiver which has access to operate server software. It enters as input into the algorithm in order to generate the priorities. The output from server is translated as a task to send text messages to the available health experts. The sketch shows the case where one finds two possibilities: there is availability for accessing a health expert or busy system. The server turns its attention to the cases where a highly priority is reported. The health expert would receive the following information: (i) patient ID, (ii) values of patient 's stability, and (iii) update patient's history. If the data server carry out evaluation resulting in a case of high priority then the patient will receive a phone call from the available health specialist, immediately. The health specialist already knows the current state and the possible states for subsequent hours. With this information the specialist might make crucial recommendations. In order to test the capabilities of an implemented eHealth service we proceed to perform a Monte Carlo simulation in the sense of select aleatory cases given a random set of priorities. The algorithm 1 has as end the aleatory generation of a set priorities or levels. On the other hand a teleconsult functionality can be translated in the contain of algorithm 2. That takes the results of algorithm 1. Let us to explain in a few details. Consider up to N people whom has sent information to a server through a text message from their cell phones. Indeed, there is available $\mathcal{P}$ health specialists the time T_h. The sender actually performs the sent of information through a mobile phone (so that, the sending process should not be troublesome). The role of receiver is that of gathering all information of people aftermaths the flooding events by using a real-time data reading. Thus the server runs a data analysis application or software, whose purpose is that of converting all arrived text messages in a txt-file with information of recent info of patients. Once the txt-file is saved, it is processed for the algorithm 2 that calculates the priorities of urgent patients. The algorithm also calculates the stabilities of people. Actually the priorities are computed through adequate usage of Eq. 6 that is needed because **high priorities are reserved for people which have been wounded due to flooding or similar situation coming from areas already with flooding.** Next

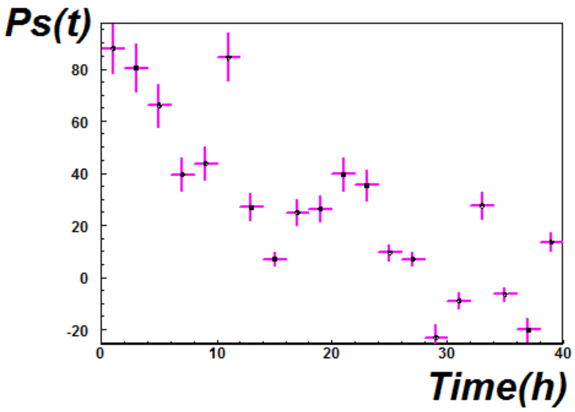

Fig. 4. Simulation of the probability of success up to 40 teleconsults for 40 hours of running the eHealth attention center.

step is to recognize those people with highest priorities and the number of available health specialists, in order to initialize the tele-consult. This step is of great importance since it might define the quality and efficiency of tele-consults [17][18][19]. For instance, γ that measures the quality of individual session and it is defined as $\gamma = \mu N_P \frac{N_F}{N_S + N_{HS}}$ where N_F and N_S the fails and successes as well as N_{HS} number of available health specialists per time unit, N_P number of peoples accessing tele-consult per time unit, and μ parameter that measures the quality of tele-consult. Is assumed that it is known the possible values of μ in terms of data server (DS) connectivity, software and hardware infrastructure (phone machine and installed applications) of both patient and health specialist (HS), and the availability of health specialists per time units. It is noteworthy that from this result the QoS measures the probability of success of call completion [17]. For the numerical input for cities of Catacaos y La Arena the resulting in a 45% and 65% respectively. It would indicate an acceptable role of the eHealth services [18][19][20][21][22][23] or aftermaths flooding events. In Fig.4 is plotted the curve of success probability for 40 hours of running the eHealth services i.e. the first two days after the beginning of the flooding, having registered up to 40 consultations, equivalent to 1 per hour.

VI. Conclusion

In this paper, we have estimated the probability of risk by using the Volterra's formalism. Basically, we have used the second order truncated Volterra series. The probabilities have been interpreted as functions depending on the distances between river and people located in Peri-urban areas. We have paid attention to the districts of "Piura" near to river because have had the impact of flooding in last summer as result of the arrival of the "El Niño" [14][15]. The probabilities obtained with the Volterra model have been used to calculate the fraction of people, to be at the risk level This results have served to simulate a model of teleconsult for a eHealth center working for 40 hours. The district of Catacaos have shown to have an acceptable probability of success for the first hours of the teleconsults yielding a values above 80% for the first two hours. Indicating that at least 2 of 3 people would be satisfied with the eHealth center [19][20][21][22][23].

References

[1] S. Boyd and L. Chua, Fading memory and the problem of approximating nonlinear operators with Voltera series, IEEE Trans. Circuits Systems, vol. CAS-32, no. 11, pp. 11501161, Nov. 1985.
[2] S. Boyd, L. O. Chua, and C. A. Desoer, Analytical foundations of Volterra series, J. Math. Control Inf., vol. 1, pp. 243282, 1984.
[3] S. P. Boyd, Volterra series: Engineering fundamentals, Ph.D. dissertation, Dept. Elect. Eng. Comput. Sci., Univ. California, Berkeley, CA, 1985.
[4] R. W. Brockett, Convergence of Volterra series on infinite intervals and bilinear approximations, in Nonlinear Systems and Applications, V. Lakshmikanthan, Ed. New York: Academic, 1977, pp. 3946.
[5] F. Bullo, Series expansions for analytic systems linear in control, Automatica, vol. 38, pp. 14251432, 2002.
[6] J. L. Casti, Nonlinear System Theory. Orlando, FL: Academic, 1985, vol. 175, Mathematics in Science and Engineering.
[7] P. E. Crouch and P. C. Collingwood, The observation space and realizations of finite volterra series, SIAM J. Control Optim., vol. 25, no. 2, pp. 316333, 1987.
[8] E. G. Gilbert, Functional expansions for the response of nonlinear differential systems, IEEE Trans. Autom. Control, vol. AC-22, no. 6, pp. 909921, Dec. 1977.
[9] Frame, Explicit solutions in two species Volterra systems, Journal of Theoretical Biology, Volume 43, Issue 1, January 1974, Pages 73-81.
[10] W. J. Rugh, Nonlinear System Theory, The Volterra/Wiener Approach. Baltimore, MD: Johns Hopkins Univ. Press, 1981.
[11] X. J. Jing, Z. Q. Lang, and S. A. Billings, Magnitude bounds of generalized frequency response functions for nonlinear Volterra systems described by Narx model, Automatica, vol. 44, pp. 838845, 2008.
[12] UNICEF Peru Humanitarian Situation Report 11 (26 June 2017). https://reliefweb.int/report/peru/unicef-peru-humanitarian-situation-report-11-26-june-2017. https://reliefweb.int/map/peru/piura-peru-flood-situation-30032017-delineation-map-monit01.
[13] Xuehua Zhao; Qiang Huang; Jingping Zhang, Impact of global climatic change on runoff in the upper reaches of the Yellow River, 2011 Second International Conference on Mechanic Automation and Control Engineering Year: 2011 Pages: 2219 - 2222.
[14] Elizabeth Wu; Sanjay Chawla, Spatio-Temporal Analysis of the Relationship between South American Precipitation Extremes and the El Nio Southern Oscillation, Seventh IEEE International Conference on Data Mining Workshops (ICDMW 2007) Year: 2007 Pages: 685 - 692.
[15] Ming-Xia He; Rui Chen; Lei Guan; Mingqiang Fang, The relationship between time series sea surface slope and El Nino event from satellite altimetry: a potential indicator, IGARSS 2001. Scanning the Present and Resolving the Future. Proceedings. IEEE 2001 International Geoscience and Remote Sensing Symposium (Cat. No.01CH37217) Year: 2001, Volume: 4 Pages: 1738 - 1740 vol.4.
[16] B Kamsu: Systemic modeling in telemedicine Volume 3, Issue 2, June 2014, Pages 5765 European Research in Telemedicine, Elsevier.
[17] B Kamsu An ontological view in telemedicine Volume 3, Issue 2, June 2014, Pages 6776 European Research in Telemedicine, Elsevier.
[18] Y Le Guen Telemedicine: No specific legal liability regime Volume 2, Issues 34, November 2013, Pages 121123 European Research in Telemedicine, Elsevier.
[19] ittman-Quinn mHealth applications for telemedicine and public health intervention in Botswana IEEExplore IST-Africa Conference Proceedings, 2011, May 2011.
[20] P. Nanda Quality of Service in Telemedicine IEEExplore Digital Society, 2007. ICDS '07. First International Conference on the, 2007.
[21] REF-14.- H. Trichilli Telemedicine in developing countries; Case of Tunisia IEEExplore, Information and Communication Technologies: From Theory to Applications, 2008. ICTTA 2008. 3rd International Conference on, April 2008.
[22] Nancy Kropf et.al Telemedicine for Older Adults Home Health Care Services Quarterly Volume 17, Issue 4, 1999.
[23] Eileen McDonald and et.al Acceptability of Telemedicine and Other Cancer Genetic Counseling Models of Service Delivery in Geographically Remote Settings Journal of Genetic Counseling April 2014, Volume 23, Issue 2, pp 221-228