Towards on Modelling Prediction of Biometric System Reliability

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Abstract. *The development of a biometric systems is undoubtedly on the rise in the number and the application areas. Modeling of system reliability and system data analysis after failure and the time of re-establishing the operating regime is of crucial importance for users of the biometric systems and also for producers of components and implementation process. Approaches for reliability analysis of biometric systems are subject to a review of numerous scientific papers. Most of them consider issues of reliability of component software applications. System reliability, considering hardware, software and user influence is to represent integral approach for mathematical modeling of system reliability and it is of crucial importance for users and for manufacturers of biometric systems.*

In this paper, the authors proposed a mathematical model to predict the reliability of biometric systems, regarding influence of the user, software and hardware considering serial dependence of components with exponential distribution of failure probability into two separate mathematical models.

Final considerations are about recovery function after failure of certain component and its representations using UML modeling technique.

Keywords- Additive model, Biometric system, reliability, exponential distribution,recovery function, UML, components

1 Introduction

Many models of reliability of biometric systems are applicable only to specific parts or components of that same system. For more complex considerations must be taken into account models based on Markov processes that consider the reliability of the system as a whole, which includes components of the system hardware and software and also interaction with an user. The basic model is an additive model which assumes a serial dependence between the components [1] (Xie & Wohlin).

The generalized biometric system, according to [2] Wayman shown in Figure 1, consists of 5 elements which are contained in all biometric systems today.

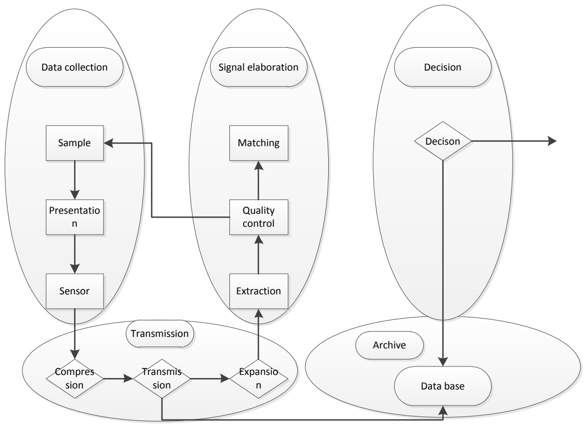

Figure 1. [2]

Each subsystem consists of the elements that contribute to the overall system quality.

Data collection subsystem consists of a biometric sample, method of sampling, and sensors that are sampled. Signal processing subsystem consists of drainage structures, quality control and comparison of samples. Decision subsystem consists of the decision mechanisms and storage subsystems.

Simplification of model described in Figure 1 can be shown on figure 2.

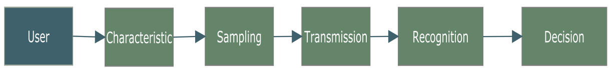

Figure 2

Schematic presentation of a biometric [1] system is a simplified representation of a system in Figure 1 and shows the serial configuration of system components dependence

2 The Definition Of The Reliability Of Biometric Systems considering software and user influence

Biometric system designers and producers are motivated to use already prefabricated components e/o modules. Component system has a high reliability expectation, no matter who is producer. Most of existing reliability models are generally described to not consider particularity of components and modules. In this paper authors will describe methodology based on mathematical model which take account of component reliability with influence of connections between components and user influence on reliability also. UML methodology in describing system and its inner interaction, simplify approach for researchers.
UML [2] is also becoming standard in the process of designing and manufacturing systems so production of component systems gets benefits from the UML representation.

Assessment of [3] generic biometric system reliability, considering software components of the system and probability of interaction with USER, can be depicted using UML modeling technique ,as given in Figure 3, which describes the Use Case diagram of certain functionalities selected by user :

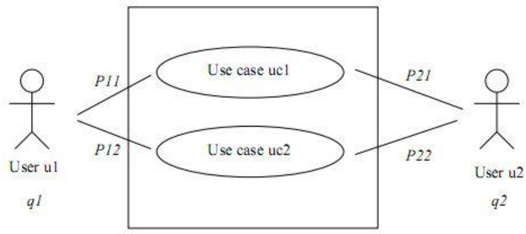

Figure 3 [3]

Diagram represent a situation that user U is to use a certain functionality of a biometric system where: q1 and q2 represent the probability that users u1 and u2 will access the system using some of its functionality.
P11 and P12 represent the probability that user u1 will use the functionality of f1 and f2, and P21 and P22 represent the same probability for the user u2.
The probability [3] of execution of considered use case diagram, is defined by the expression:

$$P(x) = \sum_{i=1}^{m} q_i * P_{ix} \quad (1)$$

Where "m" is a number of users.

Then we can consider number of execution of chosen functionalities in certain sequence afterwards to start of execution by user. Sequence of execution is defined by architecture of a system and it can be depicted as in Figure 4.

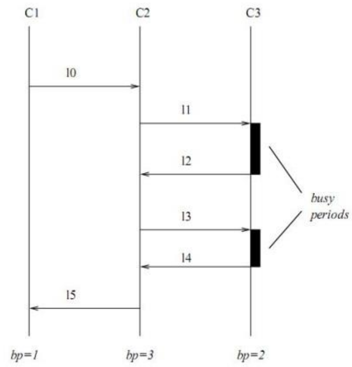

Figure 4 Sequence diagram [3]

Sequence diagram [3] play an important role in assessing the reliability of the system because they give information on how many components are involved in the execution of a scenario.
Through sequence diagrams it is simple to count the periods of availability of components in the given scenarios as shown in Figure 4.
If we are able to join a no uniform distribution to Sequence diagram in figure (4) [3] for a given use case diagram in Figure 3 then expression (1) can be expressed as:

$$P(k_j) = P(j) * f_j(k) \quad (2)$$

Where is:
fj (k) - frequency of the k-th transition of sequence diagram in the j-th case.
P (kj) – a probability of default scenarios.

The probability [4] of failure of components with known busy periods, can be given by the following expression:

$$P_{ij} = Prob(failure\ C_i\ in\ scenario\ j) = 1 - (1 - P_i)^{bp_{ij}} \quad (3)$$

Where is:
- P_{ij} - probability of component failure i in the scenario j
- bp_{ij}- occupancy time of component i in the scenario j

The expression (3) can be applied only if the following conditions are met:

- Independence of failure: the probability of failure of one component does not depend on other components
- Regularity of failure: the probability of failure of one component is equal throughout the execution of occupation period of the component

It can also show every moment of occupancy of any component of the system considering the method to be executed at that moment in the scenario

If we replace P_i with a set of method of failure probability P_i^l where is $l = l_1, \dots, l_{bp_{ij}}$ then equation (3) becomes:

$$P_{ij} = Prob(failure\ C_i\ in\ scenario\ j) = 1 - \prod_{l=l_1,\dots,l_{bp_{ij}}} (1 - P_i^l) \quad (4)$$

During system operational activity, components interact and exchange information. Then it is necessary to take into consideration occupational period of the component:

$$P_{ij} = 1 - (1 - P_i)^{bp_{ij}} \quad (5)$$

Where is θij- the probability of failure of system components and bp-busy period of the system.

$$\psi_{lmj} = (1 - P_i)^{|Interact(l,i,j)|} \quad (6)$$

Where is Ψ_{lmj}- the probability of failure connections between the components and $|Interact(l,i,j)|$_ the number of interactions between system components.

$$P_s = 1 - \sum_{j=1}^{k} P_j \left(\prod_{i=1}^{N} (1 - P_i)^{bp_{ij}} * \prod_{l,j} (1 - \psi_{lij})^{|Interact(l,i,j)|} \right) \quad (7)$$

The reliability of the system taking into account the probability of failure can be expressed as:

$$R_s = 1 - P_s = 1 - \left[1 - \sum_{j=1}^{k} P_j \left(\prod_{i=1}^{N} (1 - P_i)^{bp_{ij}} * \prod_{l,j} (1 - \psi_{lij})^{|Interact(l,i,j)|} \right) \right] \quad (7a)$$

$$R_s = \sum_{j=1}^{k} P_j \left(\prod_{i=1}^{N} (1 - P_i)^{bp_{ij}} * \prod_{l,j} (1 - \psi_{lij})^{|Interact(l,i,j)|} \right) \quad (7b)$$

3 The Definition of The Reliability of Biometric Systems considering hardware with the Components in Serial Dependence with an

Exponential Distribution of failure probability

Generally [5], [6] system reliability considering hardware components of the biometric system can be expressed according to the law of exponential distribution:

$$R_s = e^{-\lambda * t} \quad (8)$$

Where is:
R_s - System reliability
λ - Intensity of system fault
t - Required time of reliable operation of system

Proof:

$$R(t) = 1 - P(t) = 1 - \int_0^t p(t)dt$$
$$= 1 - \int_0^t \lambda * e^{-\lambda * t} dt = 1 - \lambda \int_0^t e^{-\lambda * t} dt = 1 + e^{-\lambda * t} \Big|_0^t = 1 + e^{-\lambda * t} - e^0$$
$$= e^{-\lambda * t}$$

Considering a serial dependence between of all components of the system, the failure of any component of the system may cause the failure of the entire system.
Failure intensity function λ_s in the case of a serial dependence of system components can be expressed:

$$\lambda_s = \sum_{i=1}^{n} \lambda_i \quad (9)$$

Where is:
λ_i - failure intensity of the i-th part of the system.

Failure intensity function λ_s is equal to the ratio between the number of failures in the time-frame and the functional number of components in the system, until the beginning of this interval:

$$\lambda_s = \frac{n_2(\Delta t)}{[n_1(t - \Delta t)] * \Delta t} = \frac{1}{\theta_s} \quad (10)$$

Where is:
λ_s -function of failure intensity of system
Δt - failure time of an system element
$n_2(\Delta t)$ - number of failures in certain time interval Δt
$n_1(t - \Delta t)$ – the non failed number of elements at the end of the interval Δt , or until $t - \Delta t$

The intensity of the component failure is calculated by the expression:

$$\hat{\lambda}_{EL} = \frac{\frac{1}{\Theta}}{n} = \frac{1}{\Theta \cdot n} \qquad (11)$$

Where is:

n-number of usable parts of the confidence interval $(1-\alpha) = 0,75$

Θ - lower limit of confidence for the mean time between failures

The total intensity of failure taking into consideration the number of components that are not failed in a given time can be expressed:

$$\lambda = \lambda_s + n_{el}\overline{\lambda_{el}} = \frac{1}{\theta} \qquad (12)$$

Where is:

n_{EL}- number of elements of subsystems that are not failed

Mean time between failures MTBFs can be expressed:

$$MTBF_s = \frac{1}{\lambda_s} = \theta_s \qquad (13)$$

MTFB is rather empirical data.

Calculation of reliability [4] of certain component is based on empirical data on the time of functioning and eventual failure of the component.
Problem [5] [6] [7] becomes more complex when the information about the failure doesn't exist because component worked perfectly without failure but the information about the exploitation time is available. With an assumption that for given component can be applied the rule of the exponential distribution, it is possible to determine the upper limit of confidence for the intensity of failure, in the cases of continuous operation of the system without failures.

Lower limit of confidence for the MTFB- mean time between failures $\hat{\Theta}$, for confidence interval $(1-\alpha)$ can be expressed:

$$\hat{\Theta} \geq \frac{2t_r}{\chi^2_{\alpha,2r+2}} = \frac{2t_r}{\chi^2_{0.25,2}} \qquad (14)$$

Where is:

t_r – total time of system operation
r – Number of elements that have failed
$\chi^2_{\alpha,2r+2}$ - Random variable which has a distribution

4 Special case of not-failure system

Considering (8), (10) and (14) we obtain an expression [8] [9] for the reliability of the whole system:

$$R_s = e^{-\frac{1}{\theta}*t} \qquad (15)$$

Follows that:

$$R_s = e^{-\frac{t}{\theta}} = e^{-\frac{t(\chi^2_{\alpha,2r+2})}{2t}} = e^{-\frac{\chi^2_{\alpha,2r+2}}{2}} \qquad (16)$$

Taking into account (11) we obtain an expression for the reliability of the each elements of the system:

$$R_s = e^{-\frac{t}{\theta * n}} = e^{-\frac{t(\chi^2_{\alpha,2r+2})}{2t*n}} = e^{-\frac{\chi^2_{\alpha,2r+2}}{2*n}} \qquad (17)$$

5 Recovery Function of Biometric System in UML

5.1 Recovery function definition

Generalized biometric system model[10], [11], [12] as a schematic view of Wyman biometric system model ,shown in Figure 1, that depicts serial dependence of a system components and can be approximated, in this exploitation period of time, as shown in Figure 4. as a sequence of components in serial functional dependence:

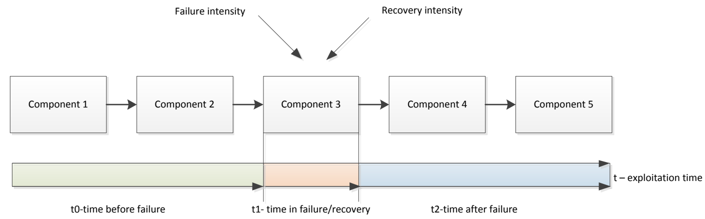

Figure 4

Supposition is that the system shown in Figure 4 is operational until time t0 without failure.

After the failure the system is recovered within time t1, and after recovery process occurs time period of re-functioning t2.

Intensity of recovery function μ can be defined as:

$$\mu = \frac{1}{MTTR} \qquad (18)$$

Where:
MTTR –mean time to repair

The process of transition from the state of failure to the state of availability, with respective probabilities of transition, can be represented as in Figure 5:

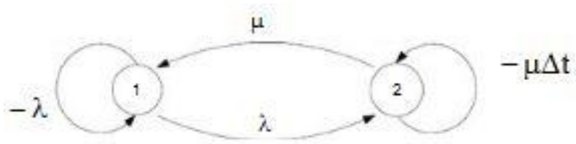

Figure 5

Condition 1 represents a functional system and condition 2 represents a system that has been repaired after a failure. The transition of system from condition 1 to 2 is represented with failure intensity function λ, the transition from condition 2 to condition 1 is defined with recovery intensity function μ.

Parameter which defines the conditions created by failure is intensity of failure of a particular component $\hat{\lambda}_{EL}$.

The intensity of the component failure can be expressed as:

$$\hat{\lambda}_{EL} = \frac{\frac{1}{\Theta}}{n} = \frac{1}{\Theta \cdot n} \qquad (11)(19)$$

Where is:

n- number of operational components in the confidence interval $(1-\alpha) = 0,75$

Θ - lower limit of confidence for the mean time between failures.

Recovery time of the system is the function of the recovery intensity as described by the expression (18).

5.2 The Conceptual Class-Diagram Model of System Recovery

During the study[12][13] of the problem of reliability of generic biometric system, object-relational approach of description of the problem provides easier and clearer description of the sequence analysis of events within the system during the verification of the failure.

Figure 6 shows the diagram of classes of the recovery of the biometric system model:

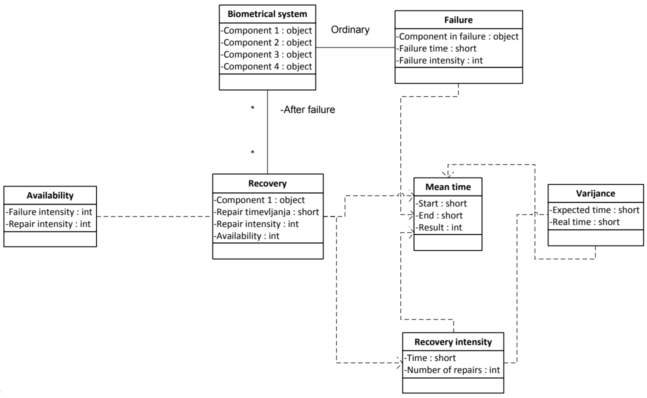

Figure 6

Class Biometric system is a set of components of that system and is in relation to class Failure which contains data on the Component exploitation (in failure or not), time of occurrence of failure and failure intensity.

Class Recovery is in relation to class Biometrical system because it contains information about the component, the time of failure, time of recovery and calculated recovery intensity of component. Class Recovery is in relation to the class Availability, which is a function of data considering failure intensity and the recovery intensity of component in certain portion of exploitation time, with the class Mean time which contains data of recovery start time, duration and results of recovery, with the class Recovery intensity. Furthermore it is possible, at the level of class diagrams to present and other factors of reliability and facilitate access to their prediction based on historical data (logs) of the system functioning.

6 Conclusion and Further Research

The reliability of biometric systems is the subject for many scientific papers, and according to that analysis, are available variety of different models of biometric systems reliability. Most of them take into account the software influence separately from hardware influence and user influence on system reliability. This study developed mathematical model for reliability prediction of a generic biometric system that consider user, hardware and software influence and assumes serial dependence of the components and the exponential distribution of failure probability of system components. Scientific contribution is expressed through mathematical model definition of biometric system reliability prediction within special case where is not possible to get failure data or in the case of perfectly working system and Recovery function consideration through mathematical and UML modeling process. The results of considerations can give relevant information about how to prevent real failure events by defining preventive maintenance intervention and respective costs of failure period in relation to the preventive maintenance costs. This mathematical prediction model can allow the prediction of system reliability in the early phase of projecting of its components regarding model of importance of influence within a system . In accordance with the above information on the exploitation of biometric systems must be part of a comprehensive analysis of the functioning and also information on recovery of the system and its functionality at any given time. The time to put the system into functional condition is often placed in clearly defined time frames that are stipulated in contracts as a SLA addenda. The parameters monitoring processes associated with the reliability of the system are often complicated and laborious so UML approach to description of problem simplifies analysis. The subject of further research will be to create an integrated mathematical model of reliability of complex systems that considers the different (ex. parallel and combined) dependency of system components with different distributions of failure probability. In accordance with this authors will define mathematical model for recovery system probability for system readiness to use.

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