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EDITOR-IN-CHIEF’S INTRODUCTION

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It is with great pleasure that Volume 2, Number 1, 2009 of the African Journal of Computing & ICT is introduced. It may be said that this journal has recorded modest patronage throughout the world since the publication of the first edition in June 2009. Topical and interesting papers in relevant areas are still welcome. The scope of papers that were received and/or published so far in the journal include science/technological policy, (wireless) communications, signal processing, systems integration, computational complexity of algorithms, software engineering, discrete structures, model identification, neural networks and human-computer interaction.

In this current edition, four reviewed research papers are published. The first paper by Vincent Akpan presents a nonlinear model identification method based on recurrent neural network, and then applies the method to chemical process engineering, specifically to a non-isothermal non-adiabatic distributed chemical reactor used for the cracking of acetone into ketone and methane. The second paper is on discrete structures and was submitted by A.O. Adeniji and S.O. Makanjuola. In the paper, a general formula for calculating the number of collapsible elements in full transformation semigroup is derived. The third paper dwells on a simulation of a method of designing a convolutional coding scheme in channel control for error detection and correction in mobile wireless time division multiple access system. The paper was submitted by O.J. Emuoyibofarhe and M.I. Bardi. The fact that usability evaluation of interactive systems is a topical issue in human-computer interaction (HCI) prompted the submission of D.E. Asuquo, ‘Dele Oluwade and S.A. Adepoju. In their paper, a user-centered approach was adopted for the usability evaluation of the websites of two Nigerian universities, namely University of Calabar and University of Port-Harcourt. It is inferred that the former is comparatively better from the perspective of users. The paper is mainly part of the M.Sc (Computer Science) research work of the first author (D.E. Asuquo) carried out under the supervision of the second author (‘Dele Oluwade).
The journal would continue to receive submitted papers at any time of the year and publish accepted papers in any of the two yearly editions. It is hoped that the number of editions would be increased in the future. Efforts are being made to publish the online edition as soon as possible. I seize this opportunity to appreciate all the (potential) authors, reviewers, editors, subscribers and advertizers.
NONLINEAR MODEL IDENTIFICATION USING RECURRENT NEURAL NETWORKS: APPLICATION TO ACETONE CRACKING

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ABSTRACT
This paper presents the formulation of a nonlinear model identification method based on recurrent neural network (RNN) Nonlinear AutoRegressive with eXternal input (NARX) model derived from dynamic feedforward neural network (DFNN) by adding feedback connection between output and input layers. The proposed identification method identifies the neural network (NN) model of an input-output system. The identified NN model is then validated using the following three different validation algorithms: (1) one-step ahead cross-validation of the training and test data predicted by the trained network; (2) Akaike’s final prediction error (AFPE) estimate of the average generalization error; and (3) 5-step prediction simulations. The algorithm has been applied to a non-isothermal non-adiabatic distributed chemical reactor (DCR) used for the cracking of acetone into ketone and methane. The neural network training and validation data are obtained from the open-loop simulation of a validated first principles DCR plant model. Simulation results show that the RNN models the reactor to a high degree of accuracy.

Keywords: Levenberg-Marquardt algorithm (LMA), nonlinear autoregressive with external input (NARX) model, nonlinear model identification, recurrent neural network (RNN).

1. INTRODUCTION
The design and the application of control algorithms require the use of a model of the controlled plant. Usually their design is based on linear modeling approximations of the plant dynamics. Then, the algorithm is applied with fixed parameter values over ranges of plant operation in which the used linear model is not valid. This approach reduces the effectiveness of predictive algorithms, which although is better than other algorithms, its full abilities are not exploited. Of course very accurate models which take into consideration all the process nonlinearities can be developed from first principles by the use of ordinary and partial differential equations. Their inclusion, however, into the real-time operation of the control algorithms involve a very large number of computations. Instead the development of nonlinear models for control and other applications in adaptive context is considerably simplified if neural network (NN) models are used which can alleviate the performance degradation of a linear model due to process nonlinearities [1] when the system is operated close to constraints.
The main advantage of using physical model (i.e., in terms of differential equations) is the ability to examine effects of physical changes and variation of the system parameters. As pointed out in [2], a physical model requires several and complex equations to reach a suitable level of accuracy with extensive computational resources and long development time. Moreover, it is impossible to embrace all priori knowledge that may exit about the system to be identified. Another problem with the physical model is that it relates to continuous-time description of the system and some information is frequently lost during the discretization process [3]. The simulation of differential equations and dynamic models to obtain training and test data for NN model development for use in different applications together with their merits have been reported in [4], [5], [6] and [7]. While this approach allows for the physical model perturbation to account for uncertainty in plant operation; it also reduces computational burden for real-time control implementation as a nonlinear discrete NN model is available immediately after the network training.

The proposed multilayer perceptron recurrent neural network (MLP RNN) identification scheme together with the formulation of the MLP RNN training algorithm is presented in Section II. Three validation algorithms proposed for validating the trained neural network are presented in Section III. In Section IV, the application of the proposed nonlinear identification algorithm to a distributed chemical reactor (DCR) used for the cracking of acetone into ketone and methane is presented. Some simulation results from the DCR process identification are also presented in this section. Conclusions drawn from this work are given in Section V.

II. NEURAL NETWORK NONLINEAR MODEL

A. Design of the Multilayer (MLP) RNN Model

The proposed architecture for the nonlinear NN model identification scheme is a multilayer perceptron recurrent neural network (MLP RNN) using the teacher forcing training method [8], [9]. This architecture places the true system in parallel with the neural network, as illustrated in Fig. 1. According to this method one can train the MLP RNN as a feedforward network by using the LMA proposed in [10] and [11].

Thus, for the MLP RNN, given the input data \( u_{\text{in}}(t) \) and output observations \( y_{\text{out}}(t) \) as:

\[
Z^n = \{[u_{\text{in}}(t), y_{\text{out}}(t)], \ t = 1,2, \ldots, N\}
\]

The first \( m \) inputs \( u_{\text{in}}^i(t) \) of \( u_{\text{in}}(t) \) is applied to an \( l_1 \)-TDL tapped-delay-lines (\( l_1\)-TDL) memory (Fig. 1). At time \( t+1 \), the first \( n \) predicted outputs \( y_{\text{out}}^i(t) \) of \( y_{\text{out}}(t) \) is fed back to the input via another \( l_2 \)-TDL tapped-delay-line (\( l_2\)-TDL) memory (Fig. 1). The contents of these two TDL memories are used to feed the
input layer of the MLP RNN (Fig. 2) to predict the state of the system. \( m \) and \( n \) corresponds to the number of past inputs and outputs used by the network for prediction; \( N \) is the total number of input-output data pair; \( N_m \) and \( N_n \) are the length of first \( m \) and \( n \) data fed to the MLP RNN (\( m \) and \( n \) are also the orders of the line memories applied to the input and feedback output signals respectively); \( l \) and \( i \) are the respective number of inputs and outputs vectors of the true system; \( l_1 \) and \( l_2 \) are the respective number of inputs and outputs fed to the MLP RNN. Thus the output is ahead of the input by one time unit. The present and past values of the network inputs \( u^l_k(t) \) are \( u^l_k(t) \), \( u^l_k(t-1) \), ..., \( u^l_k(t-m) \) which represent exogenous inputs originating from outside the network. The delayed values of the outputs on which the model output \( y^l_k(t+1) \) is regressed are \( y^l_k(t) \), \( y^l_k(t-1) \), ..., \( y^l_k(t-n) \). Thus the MLP RNN of Fig. 1 corresponds to NARX model [12] shown in Fig. 2 with the regressors (past \( m \) inputs and \( n \) outputs).

The NARX model structure for an input-output RNN model has the following structure in the predictor form [13]:

\[
\hat{y}^l_k(t) = g^l_k[\theta^l_k, \phi^l_k(t), t] + \epsilon^l_k(t)
\]

(2)

where \( \hat{y}^l_k(t) \) is the predicted output of the network; \( \phi^l_k(t) = [u^l_k(t-1), ..., u^l_k(t-m), y^l_k(t-1), ..., y^l_k(t-n)]^T \) is the regressor vector made up of \( \phi^l_k(t) \) for past inputs and \( \phi^l_k(t) \) for past outputs; \( g^l_k(\cdot) \) is an unknown unidentified nonlinear function; \( \theta^l_k \) is an unknown vector of \( d \) elements containing adjustable parameters of the network (i.e., the joint weights of the network); \( \epsilon^l_k(t) \) is a white noise independent of the inputs.

The predicted model output (2) of Fig. 1 can be expressed mathematically in terms of the network parameters as:

\[
\hat{y}^l_k(t) = F_{t+1}\left[\sum_{j=1}^{\sum_{l_1}w_{j,l}}\sum_{l=1}^{\sum_{l_2}}w_{j,l}\phi^l_k(t-1) + \sum_{l=1}^{\sum_{l_2}}w_{j,l}\phi^l_k(t) + w_j\right] + W_i
\]

(3)

where \( j \) is the number of hidden neurons; \( (w_{j,l}^l \text{ and } w_{j,l}^n) \) and \( W_{i,j} \) are the hidden and output weights respectively; \( w_j \) and \( W_i \) are the hidden and output biases; \( f_j(\cdot) \) is a linear activation function for the output layer and \( f_j(\cdot) \) is a fast hyperbolic tangent function for the hidden layer given as:

\[
f_j(\cdot) = \frac{1 - 2}{e^{2v} + 1}
\]

(4)

with \( v \) being the activation potential (or induced local field). The bias is interpreted as a weight acting on an input clamped to 1. In the present study, the joint description of “weight” implies both weights and biases.

Let the true system corresponding to \( \theta^*_k = \hat{\theta}^*_k \) be given by

\[
\hat{y}^l_k(t) = g^l_k[\hat{\theta}^*_l, \phi^l_k(t), t] + \epsilon^l_k(t)
\]

(5)

At time \( t+1 \), the \( m \) past inputs and the \( n \) past outputs are available. The predicted model output \( \hat{y}^l_k(t) \) represent the estimate of the true (desired) output. The estimate is subtracted from the true output \( y^l_k(t) \) to produce the error signal \( \epsilon^l_k(t, \theta^*_k) \). The error is used to adjust the synaptic weights so as to minimize the error, \( \epsilon^l_k(t) \). The model identification problem reduces to searching the parameter set \( \theta^*_k \in \Phi \subset \mathbb{R}^d \) and obtaining “good” estimate \( \hat{\theta}^*_k \) of \( \hat{\theta}^*_k \) using a suitable training (nonlinear optimization) algorithm.

B. Formulation of the Network Training

Algorithm

The MLP RNN network training is formulated as a total square error (TSE) problem which can be expressed as:

\[
J_{\hat{y}}(\theta^*_k, Z^N) = \frac{1}{N} \sum_{t=1}^{N} [y^l_k(t) - \hat{y}^l_k(t)]^2
\]

(6)

However, the effects of the modelling errors can be considered in terms of bias and variance errors [3]. The model parameterization contains many parameters, estimating several of these models accurately may be impossible during the training process. Moreover, as \( \theta^*_k \) contains many
parameters, the minimization of (6) may be ill-conditioned due to the effects of the bias and variance errors.

Regularization [13] imposes a bias towards zero and hence increases the bias error for finite data sets, \( N \). Thus, the effects of the bias and variance errors are minimized by augmenting the criterion (6) with a weight decay (or regularization) term \( \theta_k^T D \theta_k \). The weight decay reduces the variance error at the expense of higher bias error to find a suitable compromise where the sum of the two errors will be small.

Thus, introducing the weight decay term, (6) can be expressed as:

\[
J_N(\theta_N^*, Z^N) = \frac{1}{N} \sum_{t=1}^{N} (y^*_N(t) - y^*_N(t))^2 + \frac{1}{N} \theta_k^T D \theta_k
\]

\[
= \frac{1}{N} \sum_{t=1}^{N} (\epsilon_k^*(t))^2 + \frac{1}{N} \theta_k^T D \theta_k
\]

(7)

where \( \epsilon_k^*(t) = y^*_N(t) - \hat{y}_N^*(t) \) is the prediction error, the total square error, \( TSE = \frac{1}{N} \sum_{t=1}^{N} (\epsilon_k^*(t))^2 \) and \( D = \alpha_1 I = \begin{bmatrix} \alpha_1 & 0 \\ 0 & \alpha_2 \end{bmatrix} I \) is a diagonal matrix with \( I \) being an identity matrix and \( \alpha_j \) the multiple weight decay parameter; where \( \alpha_1 \) and \( \alpha_2 \) correspond to the weight decay values of the input-to-hidden layer and hidden-to-output layer respectively. An optimal estimate may be the value of \( \theta_k^* \) which minimizes the TSE function with a regularization term by simple weight decay, so that a “good” estimate \( \theta_k^* \) of \( \hat{\theta}_k \) is obtained by minimizing

\[
\min_{\theta_k} J_N(\theta_k^*, Z^N)
\]

(8)

In the present study, the joint weight, \( \theta_k^* \), is obtained by solving (8) using the LMA described in [10] and [11] which have been modified in (7) to accommodate the weight decay term, i.e.; by the addition of the second term in (7).

III. PROPOSED NETWORK VALIDATION ALGORITHMS

Validation involves the evaluation of the estimated model if it represents the underlying system adequately. Ideally, the validation is performed in accordance with the intended use. For instance, in online system design and control, the level of ambition may be high and it is thus necessary to apply a series of simple but standard tests to investigate particular properties of the identified NN model. It is desirable that the test (validation) set satisfies the same demands as the training set regarding the representation of the entire operating range. In the present study, three major validation tests are presented.

A. Cross-Correlation Validation

The cross-correlation validation involves the comparison between the training and validation data of the true system with their predicted values by the trained network, and the evaluation of their corresponding errors using one-step ahead predictor obtained from the minimization of (8).

The idea described in [14] is to calculate and visualize the sampled correlation functions. If the residuals (i.e. the prediction errors) contain no information about past residuals or about the dynamics of the system, it is likely that all the information has been extracted from the training set and that the model approximates the system to a sufficiently high degree. The correlation function recommended in [14] and [15] is adopted here and is stated as follows:
\( f_{\alpha}(\tau) = \frac{\sum_{i=1}^{N} \left[ \alpha_{\varepsilon}(t-\tau) - \bar{\alpha}_{\varepsilon} \right] \left[ \varepsilon^{2}(t-\tau, \theta^{*}) - \bar{\varepsilon}^{2} \right]}{\sqrt{\sum_{i=1}^{N} \left[ \alpha_{\varepsilon}(t) - \bar{\alpha}_{\varepsilon} \right] \sum_{i=1}^{N} \left[ \varepsilon^{2}(t, \theta^{*}) - \bar{\varepsilon}^{2} \right]}} \),

\[ \begin{cases} k, & \tau = 0 \\ 0, & \tau \neq 0 \end{cases} \]

where \( \alpha_{\varepsilon}(t) = y_{\varepsilon}(t) \cdot \hat{e}_{\varepsilon}(t, \hat{\theta}) \), \( k = \frac{\sqrt{\sum_{i=1}^{N} \left[ \varepsilon^{2}(t, \theta^{*}) - \bar{\varepsilon}^{2} \right]}}{\sqrt{\sum_{i=1}^{N} \left[ \alpha_{\varepsilon}(t) - \bar{\alpha}_{\varepsilon} \right]}} \),

and \( \tau \in [-20, 20] \) is to check if the correlation function lags are zero within an asymptotical interval. \( \theta^{*} \) is the identified model and \( r(\tau) \) is the residual which is computed based on \( \theta^{*} \) within the asymptotical interval \( \tau \) for the training and test data. The bars over the symbols have been introduced to specify the average of the signals i.e.:

\[ \bar{\alpha}_{\varepsilon} = \frac{1}{N} \sum_{i=1}^{N} \alpha_{\varepsilon}(t) \quad \text{and} \quad \bar{\varepsilon} = \frac{1}{N} \sum_{i=1}^{N} \varepsilon(t). \]

**B. Akaike’s Final Prediction Error (AFPE) Estimate**

The Akaike’s Final Prediction Error (AFPE) is concerned with the average generalization error estimate to verify the accuracy of the trained network [16]. The AFPE estimate is useful for selecting a suitable model structure by trying different values of the weight decay parameter \( D \) in (7). A smaller value of the AFPE estimate indicates that the trained model captures all the dynamics of the underlying system. This validation test is introduced to measure how well the model trained on the training data will perform when presented with unseen data of the process.

For the regularized criterion, with \( D = \alpha_{d} I \), the AFPE estimate \( \hat{V}_{N}^{T} \) has been derived in [17] as a function of the noise variance for the case of multiple weight decay as:

\[ \hat{V}_{N}^{T} = \frac{1}{2} \left[ \sigma_{e}^{2} \left( 1 + \frac{p_{N}^{*}}{N} \right) + \gamma_{N}^{*} \right] \]

where \( \sigma_{e}^{2} \) is the noise variance estimate [13] which can be expresses as:

\[ \sigma_{e}^{2}(\theta^{*}, Z^{N}) = \frac{1}{N} \text{tr} \left[ R_{N}^{-1} \hat{J}_{N}^{*} \right] \]

\[ p_{N}^{*} = \text{tr} \left[ R_{N}^{-1} \left[ R_{N}^{-1} + D^{-1} \right]^{-1} \right] \]

\[ \gamma_{N}^{*} = \frac{1}{N^{2}} \left( \theta^{*} \right) D \left[ R_{N}^{-1} + \frac{1}{N} D \right]^{-1} \left[ R_{N}^{-1} + \frac{1}{N} D \right]^{-1} \]

and \( \hat{J}_{N}^{*} = J_{N}^{*}(t, \theta^{*}) \) is evaluated as the Hessian. \( \text{tr} \{ \vartheta \} \) is the trace of \( \vartheta \), where \( \vartheta \) is the function being evaluated.

Expanding the total square error portion of the criterion (the training error, \( e_{i}^{2}(t) \)) around the true weights, \( \theta^{*} \), and taking the expectation with respect to \( \theta_{N}^{*}(t) \) and \( e_{i}^{2}(t) \) leads to the following.

**TABLE I**

<table>
<thead>
<tr>
<th>DCR Model Parameters</th>
<th>Numerical Values</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed temperature ( (T_{f}) )</td>
<td>1200</td>
<td>K</td>
</tr>
<tr>
<td>Feed pressure ( (P_{f}) )</td>
<td>1.58</td>
<td>atm</td>
</tr>
<tr>
<td>Temperature of the external cooling medium in the heat exchanger ( (T_{j}) )</td>
<td>1030</td>
<td>K</td>
</tr>
<tr>
<td>Volumetric flow rate ( (q_{j}) )</td>
<td>0.002</td>
<td>m(^{3})/s</td>
</tr>
<tr>
<td>Volume of the reactor ( (V) )</td>
<td>0.1</td>
<td>m(^{3})</td>
</tr>
<tr>
<td>Overall heat transfer coefficient between reactor and heat exchanger ( (U) )</td>
<td>110</td>
<td>W/(m(^{2})\cdot K)</td>
</tr>
<tr>
<td>Total heat transfer area between reactor and exchanger ( (A) )</td>
<td>160</td>
<td>m(^{2})/(m(^{3}) of the reactor)</td>
</tr>
<tr>
<td>Gas constant ( (R) )</td>
<td>8.206e(^{0} )</td>
<td>atm\cdot m(^{3})\cdot mol(^{-1})\cdot K(^{-1})</td>
</tr>
</tbody>
</table>

AFPE estimate obtained in [13] as:
\[ \hat{y}_n^* (\hat{\theta}_N^*, Z^N) = \frac{N + p_N^*}{N - p_N^*} J_n (\theta_n^*, Z^N) + \gamma_n^* \] (12)

\( \gamma_n^* \) is a positive quantity that improves the accuracy of the estimate, then the true weights in \( \theta_n^* \), is substituted for the biased estimate in \( \bar{\theta}_N^* \). As pointed out in [3], although the estimate of the final prediction error has been derived under the assumption that the true system is contained in the model structure but this works well regardless of the fact that this condition is not fully satisfied.

C. K-Step Ahead Predictions by One-Step Ahead Neural Network Predictor

This k-step ahead validation is particularly useful in relation to the predictive control strategies. In the k-step ahead simulation, the predictions of the trained network output is compared to the true training data using one-step ahead neural network predictor [13] and [17].

For the present study, a visual inspection of the one-step ahead predictions might not reveal possible problems. Suppose that two succeeding outputs are very close, \( y_n^*(t) \approx y_n^*(t - 1) \), and unless the one-step ahead prediction, \( \hat{y}_n^*(t|\theta_n^*) \), is a much worse prediction than \( y_n^*(t-1) \), the prediction error will appear to be very small. In this case, a small prediction error does not clearly imply that the model is good. Thus, it is necessary to check that \( \hat{y}_n^*(t|\theta_n^*) \), is in fact a much better prediction of \( y_n^*(t) \) than the naïve prediction, \( \hat{y}_n^*(t) = y(t - 1) \).

A useful technique used to inspect the prediction errors is the k-step ahead prediction proposed in [13] and is adopted in the present study for this validation test. The k-step ahead prediction is calculated by the one-step ahead neural network predictor and the future residuals are set to zero. The NARX model k-step ahead predictor takes the following form [3]:
\[ \hat{y}_n(t+k) \triangleq \hat{y}_n(t+k|t, \theta_n^*) \]
\[ = \hat{g}_n[\theta_n^*, \hat{p}_{\gamma_n^*}(t+k), t] \] (13)

where
\[ \hat{g}_n(\theta_n^*, \hat{p}_{\gamma_n^*}(t+k), t) = \sum_{\gamma=0}^{m} \gamma \times \prod_{\gamma=0}^{m} \gamma \]

where

IV. Application of the Proposed Identification Algorithm to a Distributed Chemical Reactor (DCR) for the Vapor-Phase Cracking of Acetone

A. The DCR Problem Formulation

To test the performance of proposed identification algorithm, we consider a distributed chemical reactor (DCR) used for the cracking of acetone into ketone and methane described in [18]; where pure acetone (feed) enters the reactor. The four inputs to the DCR are the: feed temperature (\( T_f \)), feed pressure (\( P_f \)), feed flow rate (\( q_f \)), temperature of the external cooling medium in the heat exchanger \( T_e \). The outputs (measured) of the DCR are the feed concentration (\( C_f \)) and its corresponding temperature (\( T_e \)). The volume \( (V) \) of the DCR is the independent variable. Additional description of the acetic cracking and DCR process can be found in [19].
The objective here is to identify a NN model for the 4-input 2-output DCR system by using the proposed identification algorithm. The complete mathematical model of the DCR is given in (16) and (17) at the bottom of this page; where \( \Delta H \) is the heat of reaction in J/mol, \( C_R \) is the heat capacity of acetone in J/(mol·K), \( C_b \) is the heat capacity of ketone in J/(mol·K), and \( C_l \) is the heat capacity of methane in J/(mol·K). Other DCR model parameters, their numerical values and units are summarized in TABLE 1.

B. Training the RNN for the DCR NN Model Identification

The four inputs to the DCR were chosen to be 30% of their true parameter (nominal) values to represent the dynamic operating range of the process with uncertainty in process model. The DCR process model is run for 500 simulations with an integration step of 0.002 m3 to generate 500 input-output data pair. The generated data are split into training set (80% of 500 = 400) and validation set (20% of 500 = 100). The input-output training data are scaled to zero mean and unit variance using:

\[
\begin{align*}
\xi'_n = \frac{x'_n - \bar{x}'_n}{\sigma'_{x,n}}, & \quad \eta'_n = \frac{y'_n - \bar{y}'_n}{\sigma'_{y,n}}
\end{align*}
\]

(18)

where \( \bar{x}'_n, \bar{y}'_n \) and \( \sigma'_{x,n}, \sigma'_{y,n} \) are the mean and standard deviation of the training input and target data respectively. \( x'_n \) and \( y'_n \) are the scaled inputs and outputs respectively.

After a series of trial-and-error, the effective numbers of neurons for the hidden layers is selected as 10 with two input and two output neurons for our four-input two-output system; the order of the line memories (also order of the system) are selected as \( m = 2 \) for each of the four \( m \)-TDL inputs and \( n = 4 \) each for the two \( n \)-TDL outputs. Denoting \( \alpha_i \) in \( D = \alpha_i \) (7) as \( \alpha_{d,i} \) and \( \alpha_{d,i} \) for the \( C_F \) and \( T_R \) respectively. \( \alpha_{d,i} \) is selected as \( \alpha_{d,i} = 1e^{-4} \) and \( \alpha_{d,i} = 1e^{-3} \) while \( \alpha_{d,i} \) is selected \( \alpha_{d,i} = 1e^{-5} \), \( \alpha_{d,i} = 1e^{-4} \). All the inputs to the RNN NARX model are:

\[
\begin{align*}
\phi_{x,i} (=) &= \left[ T_i(V-1), T_i(V-2), P_i(V-1), P_i(V-2),
T_i(V-1), T_i(V-2), q_i(V-1), q_i(V-2) \right] \\
\phi_{y,i} (=) &= \left[ C_F(V-1), C_F(V-2), C_B(V-3), C_B(V-4),
T_R(V-1), T_R(V-2), T_R(V-3), T_R(V-4) \right] \\
u'_i &= \left[ u'_F(V), u'_F(V), u'_B(V), u'_B(V) \right] \\
\hat{y}'_i &= \left[ \hat{y}'_F(V), \hat{y}'_B(V) \right]
\end{align*}
\]

(19)

where \( \phi_{x,i} (=) = \left[ \phi_{x,F}(V), \phi_{x,B}(V) \right], u'_i(V), \) and \( \hat{y}'_i(V) \) are the regressor structure (state vector), inputs and outputs respectively. Also, time, \( t \), has been replaced with the volume, \( V \) (both are independent variables).

\[
\begin{align*}
\frac{dC_F}{dV} &= 9.37 \times 10^{14} \times e^{-\frac{H_{mol}}{T}} \times \frac{(1 - C_F)}{q_F(1 + C_F) \times T_R} \\
\frac{dT_R}{dV} &= \frac{1}{g(C_F, T_R)} \left[ 9.37 \times 10^{14} \times e^{-\frac{H_{mol}}{T}} \times \frac{(1 - C_F)}{q_F(1 + C_F) \times T_R} \right] (-\Delta H) + \frac{U \times A}{P_{\text{atm}}} (T_i - T_R)
\end{align*}
\]

(16)

(17)

with the initial conditions that \( C_F = 0 \) and \( T_R = T_i \) for \( V = 0 \). Where

\[
g(C_F, T_R) = (1 - C_F)(a_1 + b_1T_R + c_1T_R^2) + C_F(a_2 + b_2T_R + c_2T_R^2) + C_F(a_3 + b_3T_R + c_3T_R^2) \\
= (1 - C_F)C_R + C_FC_F + C_FC_R
\]

\[
C_R = 26.65 + 0.182T_R - 45.82 \times 10^{-4}T_R^2, \quad C_F = 20.05 + 0.095T_R - 31.01 \times 10^{-4}T_R^2, \quad C_B = 13.59 + 0.076T_R - 18.82 \times 10^{-4}T_R^2,
\]

and \( (-\Delta H) = -80700 - 6.7(T_R - 298) + 5.7 \times 10^{-3}(T_R^2 - 298^2) + 1.27 \times 10^{-4}(T_R^3 - 298^3) \)
The MLP RNN is trained with the training data \((N = 400)\) for 100 epochs using the LMA proposed in Section II. After network training, the identified NN model \(\hat{\Theta}_N^*\) of \(\hat{\Theta}_N\), i.e., the joint weights, is again rescaled using:

\[
\hat{y}_N = \hat{y}_N^* \sigma_{\hat{\Theta}_N^*} + \tilde{y}_N
\]

(19)

so that the trained network can work with data taken from actual plant operation.

The trained network is validated using the algorithms highlighted in Section III. The training

\[
\begin{array}{c}
\text{(a) Feed concentration (C}_F\text{)} \\
\text{(b) Reactor temperature (T}_R\text{)}
\end{array}
\]

Fig. 3. Comparison of network output predictions of the training data to the true training data set evaluated for (a) feed concentration (C\(_F\)) and (b) reactor temperature (T\(_R\)) respectively.

\[
\begin{array}{c}
\text{(a) Feed concentration (C}_F\text{)} \\
\text{(b) Reactor temperature (T}_R\text{)}
\end{array}
\]

Fig. 4. Training errors between the true training data set and the trained network outputs predictions evaluated for (a) feed concentration (C\(_F\)) and (b) reactor temperature (T\(_R\)) respectively.

\[
\begin{array}{c}
\text{(a) Feed concentration (C}_F\text{)} \\
\text{(b) Reactor temperature (T}_R\text{)}
\end{array}
\]

Fig. 5. One-step ahead neural network predictions of the model outputs together with the observed outputs based on the target output for (a) feed concentration (C\(_F\)) and (b) reactor temperature (T\(_R\)) respectively.
and validation results for the DCR process are presented in TABLE II.

C. Simulation Results

The MLP RNN NARX model identification and validation algorithms were implemented and simulated using MATLAB® from The MathWorks [20].

The small minimum performance index (MPI) and total square error (TSE) for the network training given in TABLE II demonstrates good convergence property of the training algorithm.

The results of the network training, using the scaled data based on the application of the training algorithms are presented in Fig. 3 (a) and (b), which show a comparison of network output predictions of the training data to the true training data set evaluated for $C_F$ and $T_R$ respectively by the training algorithm. The training errors between the true training data set and the trained network outputs predictions evaluated for $C_F$ and $T_R$ are respectively shown in Fig. 4 (a) and (b). Fig. 3 and Fig. 4 demonstrate that the network has been well trained and that the NN model of the process is either overparametrized or underparametrized due to the negligible training errors of Fig. 4 (a) and Fig. 4 (b).

The simulation results for the cross-correlation validation are presented in Fig. 5 (a) and (b), which show a comparison of the network prediction of the model outputs and the target (true) outputs based on the test data set evaluated for $C_F$ and $T_R$ respectively. The prediction errors between these two outputs evaluated for $C_F$ and $T_R$ are shown in Fig. 6 (a) and (b) respectively. The comparison of the maximum validation errors between the trained network output predictions for $C_F$ and $T_R$ and their target outputs is negligible as shown in TABLE II. This relatively small validation error implies that the network has been well trained. Fig. 5 and Fig. 6 demonstrate that the network has been well trained.
and that the identified NN model approximates the process accurately to a high degree due to the relatively small validation errors of Fig. 5 (b) and Fig. 6 (b). This small error also indicates that the identified NN model approximates the nonlinear dynamics of the DCR system accurately.

The implementation of the AFPE algorithm for the chemical reactor process for the regularized criterion using the values of $\alpha$ given in (7) gives the AFPE estimates for $C_F$ and $T_R$ as $2.7608e-004$ and $3.2068e-004$ respectively (see TABLE II). The AFPE results based on regularized criterion with multiple weight decay suggest that the identified model captures the underlying dynamics of the DCR system and that the network is not over-trained [16]. This implies that the optimal network parameters [17] have been selected and that the training algorithm provided a “good” estimate $\hat{\theta}_N$ of $\theta_N$.

Following the implementation and simulation of the $k$-step ahead predictor for $k = 5$; the comparison of the 5-step ahead predictions with the observed outputs using one-step ahead neural network predictor for $C_F$ and $T_R$ are presented in Fig. 7 (a) and (b) respectively. The small MVPE from (15) for the 5-step ahead prediction simulation however suggest that the essential properties of the DCR dynamics have been captured by the network and the identified NN model can be used for predictive control applications.

V. CONCLUSION

This paper proposes a nonlinear model identification method based on MLP RNN NARX model structure. The proposed algorithm has been applied for the nonlinear model identification of a DCR used for acetone cracking. The mathematical model of the DCR process is simulated in open-loop to generate the data used for the neural network training and validation.

The NN model validation results have shown good agreement between the predicted and the true outputs. The validation result also show that the proposed nonlinear model identification method modeled the feed concentration and the reactor temperature of the DCR process to a high degree of accuracy and can be used for the acetone cracking in an industrial environment in an online fashion.

The parallelization of these algorithms for systems with fast dynamics in real-time is recommended for further studies. Furthermore, the development of an online nonlinear model predictive control (NMPC) based on neural network is also recommended for the absolute control of the $C_F$ and $T_R$ for the DCR process in real-time.

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A COMBINATORIAL PROPERTY OF THE FULL TRANSFORMATION SEMIGROUP

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ABSTRACT

Let \( c(\alpha) \) be the collapse of full transformation semigroup, \( T_n \). Then the general formula to calculate the number of collapsible elements, \( |t\alpha^{-1}| \geq 2 \) is derived for all \( n \geq 0 \), which is an extension of [1] (A.O. Adeniji and S.O. Makanjuola (2008), ‘On some combinatorial results of collapse and properties of height in full transformation semigroups,’ African Journal of Computing & ICT (Journal of the IEEE Nigeria Computer Chapter), Vol.1, No. 2, pp.61 – 63).

Keywords: Full transformation semigroup, Combinatorial property

I. INTRODUCTION.

Let \( X_n = \{1, 2, 3 \ldots n\} \) be a finite set ordered in the standard way. Let \( T_n \) denote the full transformation semigroup on \( X_n \), that is, the semigroup of all mappings

\[ \alpha: \text{Dom } \alpha \subseteq X_n \rightarrow \text{Im } \alpha \]

It is a well known fact that if \( S = T_n \) then \(|S| = n^n [4]\). Combinatorial properties of \( T_n \) have been studied over a long period of time under various guises and many interesting and delightful results have emerged (see, e.g.[5,6]). The result obtained in this paper is an extension of [1]. \( c(\alpha) \) is defined due to [10] as
Various enumerative problems of an essentially combinatorial nature have been considered in certain subsemigroups of \( T_n \) and some of which are worth mentioning in this paper. In his paper in 1990, Howie [8] considered the semigroup

\[
K(n,r) = \{ \alpha \in T_n : |Im \alpha| \leq r \}, 1 \leq r \leq n
\]

which is a two-sided ideal of \( T_n \) and \( k(n,n) = T_n \).

Also Tainiter [12] obtained in his paper that

\[
|E(s)| = r^n n^r
\]

consisting of all idempotents of \( T_n \).

In this paper, we consider a property \( c(\alpha) \) of \( T_n \) consisting of all those elements \( \alpha \) for which the number of elements having this characteristic,

\[
| \bigcup_{r \in |c(\alpha)|} |t \alpha^{-1} : t \alpha^{-1} | \geq 2 | \bigcup_{r \in |c(\alpha)|} |t \alpha^{-1} : t \alpha^{-1} | \geq 2 |
\]

is known.

II. PRELIMINARIES

For standard terms in Semigroup theory, see for example [4] or [9].

Let \( \alpha \in T_n \) be denoted by

\[
\alpha = \begin{pmatrix}
B_1 & B_2 & \ldots & B_p \\
b_1 & b_2 & \ldots & b_p
\end{pmatrix}
\]

Where \( B_1, B_2, \ldots, B_p \) are pair wise disjoint subsets of \( X_n \) called the blocks of \( \alpha \) with \( B_i \alpha = b_i, i = 1, 2, 3, \ldots, p \). Note that the image of \( \alpha \) is

\[
\text{Im} \alpha = \{ b_1, b_2, \ldots, b_p \} \quad \text{and} \quad B_1 \cup B_2 \cup \ldots B_p \subseteq X_n.
\]

If \( b_i \in B_i \) we say that \( B_i \) is stationary; otherwise it is non-stationary. If we denote by \( F(\alpha) \) the set

\[
\{ B_j \in X_n : B_j \alpha = B_j \}
\]

and by \( f(\alpha) \) its cardinal, then the number of stationary blocks of \( \alpha \) is equal to \( f(\alpha) \) as in [11].

Lemma 2.1:

Let \( \{ K_j \} \in \text{Dom} \) and \( b_j \in \text{Im} \alpha \) such that

\[
|b_j \alpha^{-1}| \geq 2.
\]

If \( b_1 \neq b_2 \neq b_3 \neq \ldots \neq b_j \) then \( \chi(n;1) = 0 \) and \( \chi(n;0) = n! \) where \( j = 1, 2, 3, \ldots, n \), \( n \in \mathbb{N} \) (Set of natural numbers).

Proof:

Let \( \{ K_j \}_{j=1}^n = |b_j \alpha^{-1}| \geq 2 \) and \( S = T_n \) such that

\[
|T_n| = \left( \begin{array}{c}
\{ K_j \} \\
\{ K_j \} \\
\{ K_j \}
\end{array} \right) \\
b_1 b_2 \ldots b_n
\]

Each \( \{ K_j \} \) is a set of two or more elements, that is, \( 2 \leq \{ K_j \} \leq n \) where \( \text{b}_n \leq n \) and \( |T_n| = n^n \). \( \{ K_j \}_{j=1}^n \) is not defined for \( |b_j \alpha^{-1}| = 1 \). By the definition of \( c(\alpha), \chi(n;1) = 0 \). Considering the case when \( q = 0 \), that is for some elements in \( |T_n| \), it implies that \( j = n \). That is, if the whole of \( n \) appear in a particular mapping \( \alpha \) then we have \( \chi(n;0) \) collapse for that mapping. Therefore, we have \( \{ K_j \}_{j=1}^n = 0 \) implies that \( |b_j \alpha^{-1}| = n! \).

\[ \therefore \chi(n;0) = |S_n| = n! \]

III. COMBINATORIAL RESULT

Our main aim here is to find \( \chi(n; q) \), (where \( q \) stands for the number of times an element is repeated as an image and \( n \) stands for the domain under consideration), which is the number of
collapse, \( |C(\alpha)| \), of full transformation Semigroups. First, we need the following definition and result. The Stirling number of the second kind, denoted by \( S(n,r) \) is usually defined as the number of partitions of an \( n \)-element set \( X_n \) into \( r \) (non-empty) subsets [2] or [3] for example. It satisfies the recurrence relation

\[
S(n, 1) = 1 = S(n, n); \quad S(n, r) = S(n-1, r-1) + rS(n-1, r)
\]

**Theorem 3.1:**
Let \( \alpha : \text{Dom} \alpha \subseteq X_n \rightarrow \text{Im} \alpha \) and \( q = |\bigcup_{b \in \text{Im} \alpha} \{b, \alpha^{-1} \mid \{b, \alpha^{-1}\} \geq 2 \}|. \) Then

\[
\chi(n; q) = \binom{n}{q}^2 (n-q)! \chi(q; q)
\]

where

\[
\chi(q; q) = \sum_{r=0}^{q} (-1)^r r! \binom{q}{r}^2 (q-r)^{q-r}
\]

and the following conditions: \( q = [2, n] \), \( n \in \mathbb{N} \), \( 0^0 = 1 \) hold.

**Proof:**
If \( c(\alpha) = q \) then there are \( n-q \) singleton blocks. Thus we may choose these \( n-q \) singleton blocks in \( \binom{n}{n-q} = \binom{n}{q} \) ways.

Similarly, the \( n-q \) images of these singleton blocks can be chosen in \( \binom{n}{n-q} = \binom{n}{q} \) ways. Tying the singleton blocks to their images in a necessarily one-one fashion can be done in \( (n-q)! \) ways. For the remaining \( q \)-elements in \( c(\alpha) \) there are \( \chi(q; q) \) possibilities. Hence the result.

An alternative to the proof above using second Stirling number of the second kind as in [10] is as follow:

**Proof:**
If \( c(\alpha) = q \), we may without loss of generality let \( c(\alpha) = \{x_1, x_2, \ldots, x_q\} \subseteq X_n \). Thus \( \alpha/\{x_{q+1}, x_{q+2}, \ldots, x_n\} \) is one-one and it is not difficult to see that the number of all possible maps for this part is

\[
\left( \begin{array}{c} n \\ n-q \end{array} \right)^2 (n-q)!
\]

For \( c(\alpha) \) there are \( \chi(q, q) \) possible maps from which the result now follows as:

\[
\chi(q, q) = \sum_{r=1}^{q} r! \binom{q}{r} (q-r)^{q-r}
\]

where \( q \leq n \) ■

Thus we have the required table as follows:

\[\text{c}(\alpha) = \{x_1, x_2, \ldots, x_q\} \subseteq X_n\]. Thus \( \alpha/\{x_{q+1}, x_{q+2}, \ldots, x_n\} \) is one-one and it is not difficult to see that the number of all possible maps for this part is
Table 3.1: Collapse in Full Transformation Semigroup

| n=0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | \( |T_n| \) |
|-----|---|---|---|---|---|---|---|-------|
| q=0 | 1 |   |   |   |   |   |   | 1     |
| 1   | 1 | 0 |   |   |   |   |   | 1     |
| 2   | 2 | 0 | 2 |   |   |   |   | 4     |
| 3   | 6 | 0 | 18| 3 |   |   |   | 27    |
| 4   | 24| 0 | 144| 48| 40|   |   | 256   |
| 5   | 120| 0 | 1200| 600| 1000| 205|   | 3125 |
| 6   | 720| 0 | 10800| 7200| 18000| 7380| 2556| 46656|
| 7   | 5040| 0 | 105840| 88200| 294000| 180810| 125244| 24409| 823543|

IV. CONCLUSION

It has been shown that the number of elements that are collapse in full transformation semigroup, for \( n \geq 0 \) and \( q \geq 0 \) can be calculated using the formula:

\[
\chi(n; q) = \binom{n}{q}(n-q)!
\]

\[
\sum_{r=0}^{q} (-1)^r r \binom{q}{r} (q-r)^{-r}
\]

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SIMULATION OF A CHANNEL CONTROL SCHEME FOR ERROR DETECTION AND CORRECTION IN WIRELESS COMMUNICATION SYSTEMS

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ABSTRACT

Previous studies have shown that the presence of noise and other impairments in communication channels causes error in data during its transmission. By coming up with an effective means of detecting and correcting errors, the rate at which erroneous data manifest is brought to minimal during communication. This paper presents an effort to simulate a simple, effective method of designing a convolutional coding scheme in channel control for error detection and correction in mobile wireless time division multiple access system. The simulation results show a 50% improvement over other method of error detection and correction which involves a combination of turbo coding and low density parity checks.

Keywords: Simulation, Channel control scheme, Error detection & correction, Wireless Communication system

I. INTRODUCTION

Due to channel distortions, transmitted data can be falsified. It is important for the receiver to detect such errors and it is desirable that the receiver can correct them as well; else the benefits of mobile communication won’t be completely gotten. Several methods have been proposed for error detection and correction in wireless communication channels. Three such techniques adopted for wireless systems are; block coding for error detection, with error-detection bits added to each message to be transmitted; convolutional coding for error correction; and, in high speed 3G systems, the use of turbo coding [1]. In this study, we
simulate the convolutional coding scheme for error detection and correction in mobile wireless communication.

II. LITERATURE REVIEW

It is generally accepted that Convolutional codes are more complicated than linear block codes, more difficult to implement and have lower code rates (usually below 0.90), but have powerful error correcting capabilities. They are popular in deep space communications, where bandwidth is essentially unlimited, but the bit error rate (BER) is much higher and retransmissions are infeasible. They are difficult to decode because they are encoded using finite state machines that have branching paths for encoding each bit in the data sequence. Several works have been reported in literature on efforts on error detection and correction coding for effective communication, some of these efforts include the works of [13],[14], and [15].

A convolutional code is a type of error-correcting code in which (a) each m-bit information symbol (each m-bit string) to be encoded is transformed into an n-bit symbol, where m/n is the code rate (n≥m) and (b) the transformation is a function of the last k information symbols, where k is the constraint length of the code.

III. THEORETICAL FRAMEWORK

In this work the model been simulated satisfies the Shannon theorem [8], [12], which states that if the information rate of a given source does not exceed the channel capacity of a given channel, then there exists a coding technique that makes possible transmission through this unreliable channel with arbitrarily low error rate. The tendered model involves the combination of an error detection and correction technique; the puncture convolutional codes and the cyclic redundancy checksum respectively [5]. The figure below gives a pictorial representation of the model [7].

Figure 3.1 Block diagram of proposed model. (Adopted and modified)

III.1 Structure of the Model

Bernoulli Random Binary Generator: Create random bits to be used as transmitted message.

1. Convolutional Encoder: A convolutional encoder takes a k-tuple m_i of message elements as the input, and generates the n-tuple c_i of coded elements as the output at a given instant i, which depends not only on the input k-tuple m_i of the message at instant i but also on previous k-tuples, m_j present at instants j<i. [10].

In general, a convolutional encoder has K memory units, counting units in parallel (which occur when \( k > 1 \)) as a single unit, so that impulse responses extend for no more than \( K+1 \) time units, and are sequences of the form

\[
g^{(1)} = (g_0^{(1)}, g_1^{(1)}, g_2^{(1)}, \ldots, g_K^{(1)})
g^{(2)} = (g_0^{(2)}, g_1^{(2)}, g_2^{(2)}, \ldots, g_K^{(2)})
\]

(1)

The impulse responses are also known as the generator sequences of the convolutional code (Cconv). From this point of view, it is possible to express the encoded sequences as

\[
c^{(1)} = u \ast g^{(1)}
c^{(2)} = u \ast g^{(2)}
\]

(2)

where the operator ‘\( \ast \)’ denotes discrete convolution modulo 2. This means that for an integer number \( l \geq 0 \),

\[
c_{i}^{(j)} = \sum_{i=0}^{K} m_{i-i}^{(j)} g_{i}^{(j)} + m_{i-1}^{(j)} g_{i-1}^{(j)} + \ldots + m_{i-K}^{(j)} g_{i-K}^{(j)}
\]

(3)

For a given code sequence \( c \) generated by the encoder of a convolutional code, the channel noise converts this sequence into the received sequence \( s_r \), which is essentially the code sequence \( c \) with errors produced in the transmission. An optimal decoder is one that is able to compare the conditional probabilities \( p(s_r/c') \) that the received sequence \( s_r \) corresponds to a possible code sequence \( c' \), and then decide upon the code sequence with the highest conditional probability:

\[
P(s_r/c') = \max_{c} P(s_r/c)
\]

(4)

This is the maximum likelihood criterion. It is in agreement with the intuitive idea of decoding by selecting the code sequence that is most alike the received sequence [6]. The application of this criterion in the case of convolutional decoding faces the fact that there are so many possible code sequences to be considered in the decoding procedure. For a code sequence of length \( l \) bits, there are \( 2^{rl} \) possible sequences, where \( rc \) is the rate of the code [3]. The maximum likelihood decoder selects a sequence \( c \), from the set of all these possible sequences, which has the maximum similarity to the received sequence. If the channel is memory-less, and the noise is additive, white and gaussian, each symbol is independently affected by this noise. For a convolutional code of rate \( 1/n \), the probability of being alike to the received sequence is measured as

\[
P(s_r/c) = \prod_{i=1}^{\infty} P(s_{ri} / c_{i}) = \prod_{i=1}^{\infty} \prod_{j=1}^{n} P(s_{ri,j} / c_{ji})
\]

(5)

where on the trellis of the code \( s_{ri} \) is the \( i \)th branch of the received sequence \( s_r \), \( c_{i} \) is the \( i \)th branch of the code sequence \( c \), \( s_{ri} \) is the \( j \)th symbol of \( s_{ri} \), and \( c_{ji} \) is the \( j \)th code symbol of \( c_{i} \), and where each branch is constituted of \( n \) code symbols.
The decoding procedure consists of selecting a sequence that maximizes the probability function. One algorithm that performs this procedure for convolutional codes is the Viterbi decoding algorithm [3].

**2. Puncture:** Removes bits from the output of the convolutional encoder.

**3. QPSK Modulator Baseband:** Adjust encoded message to prepare for transmission.

**4. AWGN Channel:** Adds random numbers to simulate noisy channel.

**5. Insert Zero:** Introduces zero to substitute for bits removed by the puncture block.

**6. Viterbi Decoder:** Deciphers the convolutional code using the Viterbi algorithm.

**7. Error Rate Calculation:** Computes the proportion of discrepancies between original and recovered messages [9].

### III.2 Punctured Convolutional Codes

Punctured convolutional codes are convolutional codes obtained by puncturing of some of the outputs of the convolutional encoder. The puncturing rule selects the outputs that are eliminated and not transmitted to the channel [10].

Puncturing increases the rate of a convolutional code and it is a useful design tool because it makes it easy to achieve convolutional with relatively high rates. This enhancement of code rate is desirable because low-rate codes are associated with a higher loss of bit rate, or a larger increase in transmission bandwidth, in comparison with unencoded transmission. The procedure is applied to a base code whose code rate is always smaller than the desired code rate, so that for a given block of k messages bits, only a selection of the total number n of coded bits that the base encoder produces are transmitted. Generally, the base code is a convolutional code of rate \( R_c = \frac{1}{2} \) which is used to construct punctured convolutional codes of rate \( \frac{n-1}{n} \), with \( n \geq 3 \) bounded above by the expression

\[
P \leq \frac{1}{2(n-1)} \left( \sum_{d=d_{\text{free}}}^{\infty} W_d \text{erfc}(\sqrt{r_d E_b N_0}) \right)
\]

In this expression, \( \text{erfc} \) denotes the complimentary error function; \( r_d \) is the code rate, and both \( d_{\text{free}} \) and \( W_d \) are dependent on the particular code we ensured that in the construction of the punctured convolutional code the trellis maintained the same state and transition structure of the mother code of rate \( R_c = 1/2 \) [6].

The punctured code has fewer branches per state than the traditional code trellis. Thus the complexity of the trellis reduced, so that it also reduces the decoding complexity using the Viterbi algorithm. In the construction of the punctured convolutional codes, we defined the puncturing rule; that is, the rule that determines which of the coded outputs are not transmitted to the channel. We did this with the use of a matrix where a ‘1’ designates that the corresponding output is transmitted, whereas a ‘0’ indicates that the corresponding output is not transmitted. The puncturing procedure has a period known as the puncturing period so that the puncturing matrix is twice its period when applied to a \( 1/2 \) rate mother code. [4]
III.3 Description of Model

In the proffered model, we included the Cyclic Redundancy checksum-256 into the system of punctured convolutional codes. It was initiated by the Institute of Electrical and Electronic Engineers as a standardized technique of error detection. ‘256’ represent the polynomial used by the technique to perform computation on the transmitted message. This maximal error detection technique which also reduces over collision probabilities, reduces the complexity of the decoder; hence improving its error correction capability [4].

IV. Simulation Results and Discussion

The Simulation was performed using Matlab 6.0 release 13, we used the intdump and pskdemod matlab functions to demodulate and detect the coded symbols using the cyclic redundancy checksum. The simulation result below shows how the proposed convolutional code was simulated to detect and correct mobile communication errors especially in a circuit switch channel of a TDMA system. It also shows the error correcting capability of convolutional codes. It demonstrates the convolutional trellis generator, poly2trellis, convenc (encoder), and vitdec (decoder). Poly2trellis was used to generate the trellis of convolutional encoder. Also, the ber (bit error rate) upper bound was calculated with bercoding.

IV.1 Performance of the Original Punctured Convolutional Codes

As shown in figure 4.1 below, the union bound is the error rate line obtained from the plot of the bit error rate and Eb/No, and thus indicates the performance of the current convolutional code in detecting and correcting errors introduced into communication channels during data or signal transfer from the transmitter to the receiver in a communication system.

![Figure 4.1: Showing the Performance of the Current Convolutional Code](image)

IV.2 Setting Parameters before Convolutional Encoding for the CSC of the TDMA System

The binary symbols of the circuit switch channel of the TDMA system before the convolutional encoding is shown in figure 4.2 below where the amplitude of the binary symbols are plotted against time. We set parameters needed for the simulation. Then we generate the binary data needed as well. The first 20 points of this data are plotted against time.
IV.3 Encoding the Information Symbols

In figure 4.3, the position of the binary symbols after convolutional encoding of the circuit switch channel access in a TDMA system is shown. The data points are a result of the intersection between the amplitude and the time being spent by the signal being transmitted. We encode the information symbols. Figure 4.3 shows the coded symbols. It should be noted that the encoded symbol rate is twice the information symbol rate.

IV.4 The in-phase and quadrature components of the noiseless QPSK signal after QPSK baseband modulation.

Figure 4.4 shows the encoded symbols through the circuit switch channel after QPSK baseband modulation. The In-phase signal is shown in light green and the quadrature signal obtained shown in purple. We convert the coded information to quaternary alphabet. Then we generate an encoding array and use it to encode the symbols. Then modulate the signal using QPSK, and implement pulse shaping. Then AWGN matlab function was used to add noise to the transmitted signal to create the noisy signal at the receiver. Then, we scale the noise power to match the coded symbol rate. The in-phase and quadrature components of the noiseless QPSK signal are plotted. This is shown below:
Figure 4.4: Showing the Encoded Symbols through the Circuit Switch Channel after QPSK Baseband Modulation

Figure 4.5: Showing Data Distortion By Noise

IV.6 Demodulation, Detection and Decoding of the Coded/received Symbols.

Figure 4.6 presents the plot of the amplitude against time for demodulated symbols through the circuit switch channel in a TDMA system. We used the initdump and pskdemod matlab functions to demodulate and detect the coded symbols using the cyclic redundancy checksum [2]. Then, they sort the gray encoding array to generate the gray decoding array and use the gray decoding array to decode the received symbols. Then convert the data to binary form. The detected symbols are plotted in blue stems with circles and the original encoded symbols are plotted in red stems with x's. The red stems of the transmitted signal are shadowed by the blue stems of the received signal. Therefore, comparing the red x's with the blue circles indicates that the received signal is identical to the transmitted signal. This is shown below:

Figure 4.6: Showing the Demodulated Symbols through the Circuit Switch Channel in a TDMA System

Figure 4.7 shows the decoded symbols through the circuit switch channel in a TDMA system. We decode the demodulated symbol stream. The decoded symbols are plotted in blue stems with circles while the original (unencoded) symbols are plotted in red stems with x's.

The red stems of the original signal are shadowed by the blue stems of the decoded signal. Therefore, comparing the red x's with the blue circles indicates that the decoded signal is identical to the original (unencoded) signal. The errors shown in the previous step in the detected symbols have been corrected. This is as shown below:

**Figure 4.7:** Showing the Decoded Symbols through the Circuit Switch Channel in a TDMA System

**IV.8 Simulation Results of the convolutional code for the circuit switch channel scheme in a TDMA system**

Figure 4.8 presents the simulation results of the convolutional code for the circuit switch channel scheme in a TDMA system. It demonstrates the proposed convolutional code simulation for a Circuit Switch Channel in a TDMA System was created. Since the empirical data for the original puncture convolutional code will take time to generate, the data are loaded in through a random number generation technique. It also compares the union bound and the simulation result of the convolutional code for the circuit switch channel scheme in a TDMA system.

From Figure 4.8 the light green line represents the slope for the original convolutional code while the blue line represents the slope of the proposed punctured convolutional code for the circuit switch channel scheme in a TDMA system, it can be observed that the proposed convolutional code for the circuit switch channel scheme in a TDMA system performs better in ensuring an error-free channel as the blue line falls beneath the green line showing that the bit error rate is lesser or negligible in the proposed convolutional code for the circuit switch channel scheme in a TDMA system than in the original convolutional code.

**Figure 4.8:** Showing the Performance of the Punctured convolutional code with CRC-256

From the graph in Figure 4.8 it can be seen that for each value of the bit error to noise ratio on the x-axis the corresponding bit error rates value for the modified punctured convolutional codes are lower than the original convolutional codes. For example taking a noise of 6db on the x-axis the corresponding value on the y-axis
with respect to the blue curve is $2 \times 10^{-4}$ while on the green slope we have $4 \times 10^{-4}$.

V. CONCLUSION

It was observed from fig. 4.8 that the final result of the design including the modified punctured convolutional code for the circuit switch channel scheme in a TDMA system performs better than the original punctured convolutional codes and the simulation results shows a 50% improvement using this scheme.

REFERENCES

A USER-CENTERED APPROACH TO WEBSITES USABILITY EVALUATION

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ABSTRACT

Usability evaluation of interactive systems has been a topical issue in human-computer interaction. People at different times and places have attempted to evaluate software, websites, and other tools to ascertain their levels of usability. The essence is to indicate the extent to which such interactive systems are easy to learn, easy to use, easy to remember as well as to determine their effectiveness, efficiency, error tolerance, aesthetics and user satisfaction. The evaluation methods applied so far have not yielded desired results in the perspective of users. This work adopts a user-centered approach to usability evaluation of two Nigerian universities’ websites (www.unical.edu.ng and www.uniport.edu.ng) by applying a systematic methodology of involving users in performing set tasks (user testing) and using the tasks completion time as metric. Data collected from the tasks completion time were statistically analyzed for usability criteria of learnability, efficiency, and satisfaction. Feedbacks were obtained from users through questionnaires on areas where improvements are desired from the sites, and the design-evaluate-redesign cycle recommended to the Universities’ Web Teams to amend poorly developed interfaces and contents. It is inferred in the paper that www.unical.edu.ng received more preference from the perspective of users due to its ability to allow quick tasks performance, fast downloads, effective navigation, error tolerance, consistency, and minimal background coloring.

Keywords and Phrases: Usability evaluation, interactive systems, human-computer interaction, user-centered approach, metric
I. INTRODUCTION

The academic sector increasingly uses the Internet as a communication medium for internal and external purpose. Apart from the publication of general information, universities’ websites may allow students and staff to apply online, answer surveys, register for e-learning sessions, get lecture notes, browse the library catalogs, send and receive e-mails, check academic results, print documents etc. Designing of usable interactive systems require considering such factors as who is going to use them, where they are going to be used, the kind of activities users are doing when interacting with the systems, the appropriateness of different kinds of interfaces, the arrangement of input and output facilities etc. A key design problem and challenge is to design the interface for users’ interaction in such a way that the system is simple to use, does not involve much training, and is robust and reliable. The desired usability goals and user experience goals need not be compromised if users’ interactions with the systems must be optimized. For a website, navigation through the system needs to be straightforward and well supported. Recent researches by Nielson [6], Donahue [3], Dumas [4], Preece et al [11] and Siegel [15] have shown that users often get frustrated and may not visit the site any longer, if the interface for interaction with the system lacks the above characteristics or a combination of them. A user interface (or human-computer interface) simply refers to the parts of a hardware and/or software system that allow a person to communicate with it. Usability testing provides a systematic approach to the evaluation of human-computer interfaces.

Generally, usability of a website simply refers to the degree of ease (or difficulty) which its users experience. There are five basic criteria for evaluating usability. These are [10] navigation, response time, content, interactivity and responsiveness. Websites usability can be tested using three cost effective methods [9]. In the first method, a panel of potential users work with the site and report on their experience via a carefully prepared questionnaire by the designer. This method is regarded to be the best. In the second method, third-party sources are used by the designers to capture basic user feedback and provide comparative metrics for similar websites. Such third-party sources include BizRate [19] and Alexa Internet [20]. The third method is the use of software agents which count words/content, monitor response times, and record interactions or keystrokes during site navigation.

In [10], a survey was conducted on 750 corporate websites for usability. It was found out that businesses whose homepages address usability and incorporate other essential design criteria report higher traffic, more repeat visitors, and greater customer satisfaction. Websites, like other interactive systems, may have a perfect hardware and software blend, follow every engineering standards and measurements, but may not be usable especially if they were designed without having the users in mind. Thus, a good user interface design is imperative for a positive human-computer interaction.

In an earlier paper [1], a comparative analysis of the websites of three Nigerian Federal Universities of Technology, namely Federal University of Technology, Owerri [21], Federal University of Technology, Akure [22], and Federal University of Technology, Yola [23], was conducted to ascertain their levels of user interface usability and whether the sites’ contents are obtainable and functional. In the paper, selected users were made to carry out set tasks to help obtain quantitative and statistically validated data. Users’ opinion on the websites’ usability goals and user experience goals were collected by administering questionnaires and these were used as feedback into the design by reporting.
performance measures or errors while findings provide a benchmark for future versions through a redesign. It was discovered that [22] was preferred by users due to the efficiency, effectiveness and satisfaction obtained by users in accomplishing tasks.

The present paper uses a similar methodology as above but instead, evaluates the websites of the University of Calabar, Nigeria (UNICAL) [24] and the University of Port Harcourt, Nigeria (UNIPORT) [25]. These sites provide access to web-based information to prospective and potential students and staff. By using a user-centered approach in evaluation, the paper’s goal is to enhance improved communication to enable users have easy, quick, and effective access to the facilities offered by the interactive systems and obtain satisfaction from their use. The findings in the paper indicate that the website of UNICAL (i.e www.unical.edu.ng ) received more preference from the perspective of users due to its ability to allow quick tasks performance, fast downloads, effective navigation, error tolerance, consistency, and minimal background coloring.

II. USABILITY EVALUATION

From its beginning, the World Wide Web (WWW) “was conceived and implemented as platform-neutral, device-independent means of accessing information” [16]. Despite this intention, a large percentage of websites today are inaccessible to users, even though accessibility guidelines have been freely and widely available for over three years. The percentages of websites that are accessible are not increasing and may even decrease with the proliferation of graphics and animation rich content over recent years. According to the World Wide Web Consortium (W3C) [17], the web has become a key resource for news, information, commerce, entertainment, classroom education, distance learning, job searching, workplace interaction, community participation, and government services. It has replaced the traditional sources of information and interaction like the schools, libraries, print materials, and discourse of the workplace. In order to help organizations make their website accessible and usable, a number of methods and tools have been developed by researchers, practitioners, and Information Technology companies.

Usability evaluation methods have been of great interest to human-computer interaction (HCI) researchers and practitioners since the 1990s, and numerous studies have been conducted comparing the effectiveness of these methods [18]. These methods include cognitive walkthrough, focus groups, GOMS (Goals, Operators, Methods, and Selection Rules), prototyping, task analysis, usability inspection, and user testing. The quality of the user experience is measured by the usability of the sites. Usability is the degree of the effectiveness, efficiency, learnability, and satisfaction users achieve when interacting with the sites. When users are able to do what they need to do quickly, they are less likely to make errors, more likely to be satisfied with the services and more likely to return to the site. The key to improving site usability and promoting positive user experiences lies in systematically identifying and correcting problems users have or may potentially have in interacting with a site.

As researchers and practitioners call for increased accountability from designers in terms of meeting the needs of all users [14], it is critical that individuals from every discipline become aware of the value of user testing for improving the usability of information interfaces. There is no doubt that user testing demonstrations can be an extremely powerful way of illustrating the potential benefits of usability analysis to a wide variety of audience. Fogg [5] opined that apart from conveying trust, reputation, credibility, and professionalism, ensuring that a website is usable can result to improved consistency in navigation flows, improved download times, decreased cost of user supports, reduced site maintenance costs, increased productivity, guaranteed repeated visits and increased revenue. The complete user testing process requires usability evaluators to study an interface, access its strengths and weaknesses, develop representative scenarios of
use, administer these scenarios to representative users, analyze and evaluate the results, and generate relevant and useful recommendations for design improvements [6, 13]. The end result of the application of a systematic user-centered approach culminating in empirical usability testing is a greatly enhanced user experience. The user-centered approach to evaluation focuses on the mindset of target users and can include the following:

- Users’ prerequisite knowledge and skills
- Users’ goals and objectives (which are often different from, and in some cases in opposition to, that of authors, designers, and/or programmers of the site).
- Users’ reactions to getting lost or frustrated or being unable to accomplish their goals.

It is a fact that usability depends on a number of factors including how well the functionality fits user needs, how well the flow through the application fits user tasks, and how well the response of the application fits user expectations. User testing is the mainstay method when it comes to usability evaluation. The past ten years have witnessed great advances in the willingness of most organizations to concede the value of usability engineering for improving their products [4]. The most fundamental usability method to acquire direct information on how people use technology and challenges faced is usability testing. The overall usability of websites, for example, continues to improve as a direct result of more attention being paid to user testing by design companies [7].

To test the usability of a website, a developer can adopt two kinds of methods namely, usability inspection method (e.g. heuristic evaluation [8]) or user testing method [7]. In performing usability testing, a representative of the target user population must be selected [12], and a usability laboratory can be used for a controlled environment.

III. METHODOLOGY

The user-centered approach to the usability evaluation of the websites of the University of Calabar and the University of Port-Harcourt involves performance test. A formal summative evaluation was conducted to document the usability characteristics of the websites against usability criteria of learnability, efficiency and satisfaction. The evaluation involved seven users each from the class of end-users, which were undergraduate students, postgraduate students, teaching staff, and non-teaching staff of the two universities.

The volunteered user testers each received a scripted, verbal introduction, which explained the purpose and goals of the test and were asked to fill out a pre-survey questionnaire, which the evaluator used to gather their demographic information. The twenty-eight (28) users who volunteered for the test include 18 males (64.29%) and 10 females (35.71%), as represented in Table 3.1 below.

<table>
<thead>
<tr>
<th>Table 3.1: Sex Distribution of the Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>Female</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

From Table 3.2 below, 71.43% of the participants were within 16-25 years range and 50% of them were male while 21.43 were female. Out of the 5 participants within the age range of 26-35, 3.57% were male while 14.29% were female. Again only 7.14% male participants and 3.57% female participants were within the age ranges of 36-45 and 45-above respectively.
Table 3.2: Age Distribution by Sex of the Participants

<table>
<thead>
<tr>
<th>Age range (years)</th>
<th>Frequency</th>
<th>Percentage (Male)</th>
<th>Cumulative Percentage (Male)</th>
<th>Frequency</th>
<th>Percentage (Female)</th>
<th>Cumulative Percentage (Female)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16-25</td>
<td>20</td>
<td>71.43</td>
<td>14 (50.00%)</td>
<td>6</td>
<td>21.43%</td>
<td></td>
</tr>
<tr>
<td>26-35</td>
<td>5</td>
<td>17.86</td>
<td>1 (3.57%)</td>
<td>4</td>
<td>14.29%</td>
<td></td>
</tr>
<tr>
<td>36-45</td>
<td>2</td>
<td>7.14</td>
<td>2 (7.14%)</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>≥45</td>
<td>1</td>
<td>3.57</td>
<td>1 (3.57%)</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>28</td>
<td>100.00</td>
<td>18 (100.00%)</td>
<td>10</td>
<td>100.00%</td>
<td></td>
</tr>
</tbody>
</table>

The status distribution of the participants from Table 3.3 indicates that 53.57% of the participants used for the user testing were male undergraduate students while 25% were female undergraduate students. 10.71% were male postgraduate students while 25% were female undergraduate students. Finally, 7.14% of the staff were female, with no male staff.

Table 3.3: Status Distribution of the Participants by Sex

<table>
<thead>
<tr>
<th>Status</th>
<th>Frequency</th>
<th>Percentage (Male)</th>
<th>Cumulative Percentage (Male)</th>
<th>Frequency</th>
<th>Percentage (Female)</th>
<th>Cumulative Percentage (Female)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undergraduate</td>
<td>22</td>
<td>78.57</td>
<td>15 (53.57%)</td>
<td>7</td>
<td>25.00%</td>
<td></td>
</tr>
<tr>
<td>Postgraduate</td>
<td>4</td>
<td>14.29</td>
<td>3 (10.71%)</td>
<td>1</td>
<td>3.57%</td>
<td></td>
</tr>
<tr>
<td>Staff</td>
<td>2</td>
<td>7.14</td>
<td>2 (7.14%)</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>28</td>
<td>100.00</td>
<td>18 (100.00%)</td>
<td>10</td>
<td>100.00%</td>
<td></td>
</tr>
</tbody>
</table>

The performance test consisted of series of tasks that the volunteered user testers carried out while the evaluator noted time (in seconds (s)) to complete each task by each user with a stopwatch. Errors encountered where tasks are not accomplished were also noted. The set of tasks completed on each of the sites were:

* Task 1: Locate the university historical perspective
* Task 2: Locate the university postgraduate school
* Task 3: Locate the university fees schedule for undergraduate students
* Task 4: Locate faculty of science
* Task 5: Locate the university Alumni

The usability test was conducted in a computer laboratory under a controlled environment fully air-conditioned. Accessibility to the sites was granted to the participants through a full multimedia digital computer with 100Mbps Internet connection speed and Windows Xp unlimited operating systems using Windows Explorer as the web browser. After concluding the test, the users completed a post-survey questionnaire to gauge their responses to the
IV. RESULTS

Table 4.1 and Table 4.2 below indicate the time taken by each user tester to complete each set task on the websites.

Table 4.1: Time to complete tasks on www.unical.edu.ng

<table>
<thead>
<tr>
<th>User tester</th>
<th>Task 1</th>
<th>Task 2</th>
<th>Task 3</th>
<th>Task 4</th>
<th>Task 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>User tester1</td>
<td>8.56</td>
<td>16.62</td>
<td>7.91</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester2</td>
<td>7.45</td>
<td>17.89</td>
<td>9.74</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester3</td>
<td>7.41</td>
<td>16.45</td>
<td>5.78</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester4</td>
<td>7.78</td>
<td>17.08</td>
<td>13.6</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester5</td>
<td>9.17</td>
<td>11.28</td>
<td>10.1</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester6</td>
<td>10.41</td>
<td>12.87</td>
<td>9.70</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester7</td>
<td>8.18</td>
<td>13.78</td>
<td>8.19</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester8</td>
<td>8.11</td>
<td>12.01</td>
<td>6.99</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester9</td>
<td>9.04</td>
<td>15.42</td>
<td>7.88</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester10</td>
<td>10.17</td>
<td>12.56</td>
<td>10.2</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester11</td>
<td>8.45</td>
<td>14.71</td>
<td>9.56</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester12</td>
<td>8.19</td>
<td>19.45</td>
<td>11.3</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester13</td>
<td>12.11</td>
<td>14.12</td>
<td>9.18</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester14</td>
<td>8.95</td>
<td>13.17</td>
<td>8.89</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester15</td>
<td>7.85</td>
<td>15.06</td>
<td>7.23</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester17</td>
<td>9.59</td>
<td>16.16</td>
<td>8.39</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester18</td>
<td>8.27</td>
<td>16.27</td>
<td>9.40</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester19</td>
<td>8.98</td>
<td>13.53</td>
<td>8.67</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester20</td>
<td>7.85</td>
<td>12.45</td>
<td>9.67</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester21</td>
<td>8.14</td>
<td>14.23</td>
<td>7.87</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester22</td>
<td>8.89</td>
<td>14.56</td>
<td>9.34</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester23</td>
<td>7.23</td>
<td>11.42</td>
<td>8.29</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester24</td>
<td>8.48</td>
<td>13.38</td>
<td>8.34</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester25</td>
<td>9.23</td>
<td>13.11</td>
<td>9.04</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester26</td>
<td>9.86</td>
<td>11.12</td>
<td>7.83</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester27</td>
<td>8.45</td>
<td>16.34</td>
<td>7.83</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>User tester28</td>
<td>8.38</td>
<td>15.31</td>
<td>8.46</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.2: Time to complete task on www.uniport.edu.ng

<table>
<thead>
<tr>
<th>User testers</th>
<th>Task 1</th>
<th>Task 2</th>
<th>Task 3</th>
<th>Task 4</th>
<th>Task 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>User tester1</td>
<td>13.56</td>
<td>9.35</td>
<td>30.5</td>
<td>1</td>
<td>7.83</td>
</tr>
<tr>
<td>User tester2</td>
<td>10.79</td>
<td>7.91</td>
<td>21.3</td>
<td>5</td>
<td>14.0</td>
</tr>
<tr>
<td>User tester3</td>
<td>21.15</td>
<td>18.69</td>
<td>26.6</td>
<td>0</td>
<td>21.2</td>
</tr>
<tr>
<td>User tester4</td>
<td>11.58</td>
<td>10.17</td>
<td>22.5</td>
<td>7</td>
<td>17.0</td>
</tr>
<tr>
<td>User tester5</td>
<td>9.62</td>
<td>8.87</td>
<td>19.1</td>
<td>5</td>
<td>10.1</td>
</tr>
<tr>
<td>User tester6</td>
<td>12.67</td>
<td>10.12</td>
<td>20.0</td>
<td>4</td>
<td>11.0</td>
</tr>
<tr>
<td>User tester7</td>
<td>11.05</td>
<td>21.65</td>
<td>18.5</td>
<td>5</td>
<td>8.34</td>
</tr>
<tr>
<td>User tester8</td>
<td>12.45</td>
<td>12.11</td>
<td>26.5</td>
<td>6</td>
<td>9.01</td>
</tr>
<tr>
<td>User tester9</td>
<td>10.14</td>
<td>8.91</td>
<td>19.5</td>
<td>6</td>
<td>11.0</td>
</tr>
<tr>
<td>User tester10</td>
<td>16.18</td>
<td>19.87</td>
<td>24.9</td>
<td>8</td>
<td>15.9</td>
</tr>
<tr>
<td>User tester11</td>
<td>11.34</td>
<td>7.78</td>
<td>16.6</td>
<td>12.6</td>
<td>-</td>
</tr>
</tbody>
</table>
The blank columns indicate participants’ non-performance of tasks due to site content unavailability and absence of links to navigate. For instance, www.unical.edu.ng has Postgraduate School and Alumni as orphan pages since they are yet to be developed.

V. DISCUSSION OF RESULTS

Table 5.1 below indicates that most of the participants have more than 3 years experience with using the computer and up to 3 years experience with using the Internet. Similarly, Table 5.2 indicates that 50% of the participants surf the Internet for up to 3 hours.

Table 5.1: Participants Experience in using the Computer and the Internet

<table>
<thead>
<tr>
<th>Usage</th>
<th>Never</th>
<th>&lt;1 year</th>
<th>1-3 years</th>
<th>&gt;3 years</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer</td>
<td>0</td>
<td>2</td>
<td>8</td>
<td>18</td>
<td>28</td>
</tr>
<tr>
<td>Internet</td>
<td>0</td>
<td>2</td>
<td>14</td>
<td>12</td>
<td>28</td>
</tr>
</tbody>
</table>

Table 5.2: Number of hours participants spend weekly on the Internet

<table>
<thead>
<tr>
<th>Number of hours used</th>
<th>Frequency</th>
<th>Percent</th>
<th>Valid percent</th>
<th>Cumulative percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1 hour</td>
<td>4</td>
<td>14.29%</td>
<td>14.29%</td>
<td>14.29%</td>
</tr>
<tr>
<td>1-3 hours</td>
<td>14</td>
<td>50.00%</td>
<td>50.00%</td>
<td>64.29%</td>
</tr>
<tr>
<td>&gt;3 hours</td>
<td>10</td>
<td>35.71%</td>
<td>35.71%</td>
<td>100.00%</td>
</tr>
<tr>
<td>Total</td>
<td>28</td>
<td>100.00%</td>
<td>100.00%</td>
<td></td>
</tr>
</tbody>
</table>

The average time to complete tasks on each site is shown below in Table 5.3, indicating that the same tasks were performed faster on www.unical.edu.ng than on www.uniport.edu.ng. Figure 5.1 indicates a graphical representation of the average task completion time on each site, where the tasks are on the horizontal axis while the average time is on the vertical axis. This also indicates that usability goals of learnability and efficiency were highly obtained from www.unical.edu.ng, thereby leading to greater user satisfaction.

Table 5.3: Average time to complete tasks on each site

<table>
<thead>
<tr>
<th>Institution</th>
<th>Task 1 Average (s)</th>
<th>Task 2 Average (s)</th>
<th>Task 3 Average (s)</th>
<th>Task 4 Average (s)</th>
<th>Task 5 Average (s)</th>
<th>Total Average (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNICAL</td>
<td>12.3</td>
<td>20.3</td>
<td>15.3</td>
<td>14.92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UNIPORT</td>
<td>12.3</td>
<td>11.64</td>
<td>20.39</td>
<td>-</td>
<td>14.92</td>
<td></td>
</tr>
</tbody>
</table>
VI. CONCLUSION AND RECOMMENDATIONS

This research was carried out to perform a user-centered approach to the usability evaluation of two Nigerian university websites, namely University of Calabar website and University of Port-Harcourt website. For the purpose of efficient redesign of these websites, the following recommendations would be useful to the web team of the universities:

- The web site design, including page layout, use of colors, and placement of page elements, should be consistent to give users a standard look and feel of the website.
- The web site should not contain elements that are distracting or irritating to users, such as scrolling text, marquees, and constant running animations.
- The web site should contain no orphan page. Every page should contain at least a link up to the home page and some indication of current page location, such as site map or menu.
- The placement of site map or menu should be consistent so that users can easily recognize them and identify the targeted link.
- Standard link colors should be used so that user can easily differentiate links that have been visited and those that have not.
- Information should be up-to-date and outdated pages should be replaced.
- The web site should respond according to users’ expectation. This includes standard use of graphical user interface widgets such as radio buttons for selecting one among many options.
- Meaningful words should be used to describe the destination of a hyperlink. This will save the users’ time by not going to unnecessary pages.

Postscript

This paper is mainly part of the M.Sc (Computer Science) project work of the first author written under the supervision of the second author.

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