An Overview of the Possibilities of the Variational Analysis for Exploration of Electric Circuits

Emil Panov and Miroslava Doneva

Abstract – The paper presents an overview of the variational analysis in combination with the transferring coefficients of the electric circuits (EC). In the reference papers [1 - 9] the methodologies for DC, AC and transient analysis of linear and non-linear EC are developed. Some examples are presented in order to illustrate the approach.

Keywords – variational approach, variational analysis of electric circuits, basic theorems for variational analysis, methodologies for variational analysis.

I. INTRODUCTION

The variational approach is a powerful tool for analysis in mechanics, field theory, quantum mechanics and some other areas of modern science. The first author of the present paper developed four new theorems [1, 5] and the first systematical methodologies for variational analysis of EC in circuit theory [1-6].

Two theorems [1] can be used directly for the variational analysis of all types of regimes in a given linear EC (LEC), because they introduce the bases of such a type of analysis for EC.

First theorem: For each EC, among all sets of currents, which formally satisfy Kirchhoff’s current law (KCL) for the nodes of the circuit, there is only one set of currents, for which the instantaneous power of each current source has an extremum (a minimum or a maximum), if this power is not equal to zero. And this set of currents is the only one, which satisfies the equations using Ohm’s and Kirchhoff’s laws for the circuit.

Second theorem: For each EC, among all sets of voltages, which formally satisfy Kirchhoff’s voltage law (KVL) for the loops of the circuit, there is only one set of voltages, for which the instantaneous power of each voltage source has an extremum (a minimum or a maximum), if this power is not equal to zero. And this set of voltages is the only one, which satisfies the equations using Ohm’s and Kirchhoff’s laws for the circuit.

The variational analysis of harmonic LEC is comfortably to be introduced in combination with the phasor approach, because of the possibility for algebrization of the solutions. That can be achieved by the help of the next two theorems [5].

Third theorem: For each harmonic LEC, there is only one set of complex branch currents, for which the apparent pseudo-power of any of the current sources in the explored circuit has an extremum (a minimum or a maximum), where is the complex pseudo-power of the given source and is the complex voltage drop across it.

Fourth theorem: For each harmonic LEC, there is only one set of complex voltage drops across its elements, for which the apparent pseudo-power of any of the voltage sources in the explored circuit has an extremum (a minimum or a maximum), where is the complex pseudo-power of the given source and is the complex current, flowing through it.

I. VARIATIONAL ANALYSIS OF EC

A. SHORT THEORY OF THE VARIATIONAL ANALYSIS OF DC AND AC LEC

The variational analysis of one LEC working at DC regime by the help of the the basic laws for EC can be conducted by the following methodology:

1) A reference source (of e.m.c. with a current or e.m.f. with a voltage ) is selected in the circuit being studied. A pair of terminals (a) and (b), separating the circuit into a reference source and a resistive part, is introduced, while all other sources are considered to be resistors according to the compensation theorem with positive or negative resistances or .

2) A number of transferring coefficients are introduced in relation to the currents through the elements (the voltage drops upon them) having in mind KCL (or KVL).

3) One equation is created by the help of the balance of powers, where the power of the reference source is on the left hand side (LHS) and on the right hand side (RHS) the powers of the resistive elements are situated:

\[ P_i = u_j \hat{I}_k = \text{const.} = R_j (k_j) \hat{I}_k^2 + R_k (k_j) \hat{I}_j^2 + \ldots + R_s (k_s) \hat{I}_s^2 + \ldots + \sum_{q=1}^{\infty} \left[ \pm R_q (k_q \cdot \hat{I}_k^2) \right] + \sum_{r=1}^{\infty} \left[ \pm R_r (k_r \cdot \hat{I}_j^2) \right] \]

or
\[
P_{j} = e i_{j} = \text{const.} = \\
= G_{1}(k e_{1})^{2} + G_{2}(k e_{2})^{2} + \ldots + G_{p}(k e_{p})^{2} + \\
+ \sum_{q=1}^{n} (\pm G_{aq}(k e_{q})^{2})^{2} + \sum_{q=1}^{n} (\pm G_{bj}(k e_{j})^{2})^{2}.
\] (2)

4) A system of \((m-1)\) equations is created by the help of KVL (or KCL) and the system is solved taking into account one of the coefficients to be a parameter, for example \(k_{1}\).

5) The equation for the power (1) or (2) is differentiated by \(k_{1}: \frac{\partial P_{j}}{\partial k_{1}} = 0\) or \(\frac{\partial P_{j}}{\partial k_{1}} = 0\). In the last equation, we have to substitute \(R_{eq} = \frac{e_{j}}{i_{j}(k_{1})}\) and \(R_{eq} = \frac{u_{eq}(k_{1})}{j_{s}}\), and that equation can be solved in respect of \(k_{1}\) analytically or by a suitable numerical method. Based on the obtained value of the transferring coefficient \(k_{1}\), the other \((m-1)\) coefficients are calculated, as well as the currents and voltages of the circuit.

Example 1: A circuit is given in Fig. 1 with the following parameters: \(R_{1} = 30\Omega; \quad R_{2} = 20\Omega; \quad R_{3} = 10\Omega; \quad j = 5A; \quad e = 40V\). Determine the branch currents \(i_{1}, i_{2}\) and \(i_{3}\) by the variational approach.

Solution:

The source of e.m.c. \(j\) is selected for a reference source. The resistive part of the circuit comprises the resistances \(R_{1}, R_{2}, R_{3}\) and \(R_{eq} = \frac{e}{j_{s}}\). A transferring coefficient \(k\) is introduced for the current \(i_{2}\), i.e. \(k = \frac{i_{2}}{j}\), and applying formally KCL for node (1), we have: \(i_{1} = j, \quad i_{2} = k j, \quad i_{3} = (1-k) j\).

Then, the equation for the balance of powers for the circuit is created - its LHS represents the power of the circuit’s reference source, which is assumed to be a constant, and its RHS is a sum of the resistive elements’ powers.

\[
P_{j} = u_{eq}j = \text{const.} = \\
= R_{1}j^{2} + R_{2}(k j)^{2} + R_{3}[(1-k) j]^{2} + R_{4}[(1-k) j]^{2}.
\] (3)

Equation (3) is differentiated by \(k\) and the result is as follows: \(\frac{\partial P_{j}}{\partial k} = 0\). After the differentiation of equation (3), we substitute \(R_{j}(k) = \frac{e}{(1-k)j}\) and then, it follows, that \(k = 0.6\).

The branch currents we’ve been looking for in the circuit are the following: \(i_{1} = j = 5A, \quad i_{2} = k j = 3A\) and \(i_{3} = (1-k)j = 2A\).

In Fig.2 the dependence of the power of the reference source \(P_{j}\) versus the value of the transferring coefficient \(k\) is presented.

![Fig. 2. The power of the reference source \(P_{j}\) versus \(k\).](image)

The minimum of \(P_{j}\) is very well seen from that graph.

The variational analysis of harmonic LEC is similar to the DC analysis and it must be conducted in combination with the phasor approach. The methodology for analysis of that regime needs the introduction of the complex pseudo-power of the reference source: \(S_{j,pseudo}\) or \(S_{j,pseudo}\). The methodologies, which combine the variational approach with the loop analysis or the nodal approach for both regimes (DC and AC) are presented in papers [5, 6].

B. SHORT THEORY OF THE VARIATIONAL ANALYSIS OF DC NON-LINEAR EC

In circuit theory there are no well-developed overall analytical methods for exploration of DC regimes by the help of the variational approach. So far, the known methods for variational approach are particular and they provide a solution to specific types of non-linear problems. The application of the variational approach with transferring coefficients for analysis of non-linear EC can be done by applying common methodologies, the same for each non-linear circuit working at DC regime. The variational analysis with transferring coefficients can be applied to any non-linear electric circuit, regardless of the number and the type of the included non-linear elements. The three methodologies for analysis, which were introduced in paper [8], allow the application of the
variational approach for analysis of non-linear EC using directly the basic laws for EC, the loop analysis or the nodal approach.

C. VARIATIONAL APPROACH FOR ANALYSIS OF TRANSIENT PROCESSES IN NON-LINEAR EC

The analysis of transient processes in EC by the help of the variational approach needs a little bit different procedure, because the basic calculation technology is numeric one (especially for the analysis of non-linear electric circuits) [9].

The methodology for numeric variational analysis of the transient processes in one EC (for example with one reactive element) has the following steps:

1) A reference source is selected in the circuit being studied. The other sources can be substituted by positive or negative resistances \( R_{op}(t) \) or \( R_{on}(t) \) according to the compensation theorem.

2) A number of \( m \) transferring coefficients \( k_1, k_2, \ldots, k_m \) are introduced in relation to the currents flowing through the elements (the voltage drops upon them).

3) One differential equation can be created for the explored circuit of the following normalized form:

\[
\frac{dk_i(t)}{dt} = f[k_i(t); R_1; \ldots; R_i; C (or L)] ,
\]

which will be the predictor for the calculating process. Then, several initial values of \( k_i(t) \) can be calculated by the help of the method Runge – Kutta – 4 for the first \( p \) steps with a step size \( h \) in the time interval \([t_0; t_p]\).

4) Another equation can be created on the base of the balance of powers for the instantaneous powers of the elements of the explored circuit:

\[
\int_{t_0}^{t} p_{\text{re}}[k_i(t)] dt = W_{\text{re}}[k_i(t)] - W_{\text{re}}[k_i(t_0)] ,
\]

where \( p_{\text{re}} \) is the instantaneous power of the reactive element and \( W_{\text{re}} \) is the corresponding accumulated energy. That equation will be the corrector of the calculation process. The procedure is maintained by the usage of an iteration procedure and a numeric integration formula of Newton – Cotes of rank higher than 4 (for example 6th order integration formula).

5) By the help of the predictor – equation (4), we can get the next value \( k_i(t_{p+1}) \), which we can improve by the corrector – equation (5).

**Example 2:** A non-linear circuit is presented in Fig. 3, where: \( R_1 = 120 \Omega \); \( R_2 = 5 \Omega \); \( R_3 = 0.2 \Omega \); \( j = 25/12 A \); \( i_c(t) = 0.5.3.2^2 \). Find the current flowing through the coil \( i_c(t) \) by the help of the variational approach.

Solution:
The exact solution of that task is as follows:

\[ i_c(t) = k(t) \]

\[ i_c(t) = 0.5 \left( \frac{3 - 2e^{-25t}}{1.5 + e^{-25t}} \right)^2 A. \]

**Fig. 3. The circuit from example 2.**

The explored circuit contains a single non–ideal current source. The current flowing through the non–linear coil can be expressed as: \( i_c(t) = k(t) \).

Then:

\[ u_i(t) = \frac{dV_i(t)}{dt} = \frac{d}{dt} \left[ \frac{\sqrt{2}i_c(t)}{2} \right] = \frac{dk(t)}{dt} \sqrt{\frac{j}{2k(t)}} \]

and

\[ i_c(t) = f[1 - k(t)]. \]

Using KCL and KVL we can express the voltage drop \( u_i(t) \), i.e. \( u_i(t) = R_1i_c(t) = R_i[f[1 - k(t)] \right) \) and we can also find the connection among \( u_i(t) \), \( i_c(t) \) and \( u_i(t) \):

\[ u_i(t) = R_i i_c(t) + u_i(t). \]

From here, we receive the predictor equation:

\[ \frac{dk(t)}{dt} = \sqrt{\frac{2k(t)}{j}} \left[ R_i - (R_1 + R_2)k(t) \right]. \]

The corrector for the calculation process will have the following form:

\[ \int_{t_0}^{t} [p_i(t) - p_{R_i}(t) - p_{R_c}(t)] dt = \int_{t_0}^{t} p_i(t) dt , \]

i.e. \( k(t) = \left[ \frac{2.5\sqrt{1.5}}{2} \left[ R_i (k(t) - (R_1 + R_2)k(t)) dt \right] + k(t) \right]^{1/2} . \)

Here, the numeric integration can be fulfilled by the 6th order Newton-Cotes formula. After we have already improved the six initial values of the transferring coefficient \( k(t) \), we can improve the seventh one - \( k(t) \), too.

In Fig. 4 the relative error \( d \) is presented for two calculation procedures – the Runge – Kutta – 4 method and the optimized numeric solution of the variational approach. Here, the step size is accepted to be \( h = 1/3 ms \).
The variational analysis with the transferring coefficients is a new approach for analysis of EC. May be it is the eleventh one according the classification of the authors of the paper. Its application is supported by the introduction of four new theorems for EC, two rules for introduction of the transferring coefficients and several methodologies for analysis of DC, AC regimes in EC and transient processes, too.

The variational analysis is more difficult to use compared with the well-known methods for analysis of EC, but it has something additional compared with the rest of the methods. All methods obey to two basic laws of nature - the charge conservation law (with its consequence - KCL) and the energy conservation law (with its consequence - KVL). The variational analysis except them uses also the balance of powers, which is a consequence of the least action principle, which all physical processes in nature obey to. This fact gives an additional tool to the variational approach to have an exclusive instrument to precise the errors of the calculated values of the currents and the voltages in the explored EC. Except that, the variational analysis can be accomplished in matrix form, too [3, 4] – a fact, which makes that approach able to use automated computer-aided calculations. So, circuit theory may become only more powerful after the development and the introduction of the new methodologies for variational analysis of EC by the help of the transferring coefficients.

The proposed methodology for variational analysis of transient processes in non-linear EC can be ever introduced successfully, because we can always choose a corrector of higher order, compared with the order of the predictor, having in mind that the integration equations of Newton-Cotes form an infinite family of high-precision formulas. The truncation error of the method Runge –Kutta-4 is 
\[ e_{x_k} = \frac{h^5}{5!} f^{(4)}(\xi), \]
where \( \xi \) is some point within the time interval of the last step \( h \) of the calculation process. The sixth order integration formula of Newton-Cotes has an error:
\[ e_{x_{NC}} = -\frac{h^7}{1400} \left[ 10 f^{(5)}(\xi) + 9 h^2 f^{(4)}(\eta) \right], \]
where \( \xi \) and \( \eta \) are some points within the integration interval \( [t_i; t_{i+1}] \). So, for \( h << 1 \) it is clear, that \( e_{x_{AA}} > e_{x_{NC}} \), which allows Newton-Cotes formulas of higher order to be in the base of the corrector integration equations.

The proposed variational approach is more complex compared with the classic solutions. It is better to use it for analysis of transient processes in non-linear electric circuits, especially in cases when there are no exact classic solutions. The optimization procedures implemented in the variational method gives the possibility to improve the numeric solutions and to increase the accuracy of the final results.

\[ \text{REFERENCES} \]

Laboratory Equipment for Energy Accumulation from Renewable Sources

Silviya Letskovska¹, Kamen Seymenliyski¹, Ginko Georgiev¹

Abstract – The goal of this work is to analyse the system for energy production using renewable energy sources. One of the main aspects is education of students. The method of work is based on production of hydrogen, accumulation and reverse transformation using photovoltaic and fuel cell.

Keywords – Photovoltaic, Fuel cells, Hydrogen, Electrical energy, Renewable energy sources.

I. INTRODUCTION

The supply of electrical energy for the users can be successfully realized with the complex use of the energy from renewable energy sources (RES) and energy accumulation. This gives additional possibilities for developing of renewable energetics, particularly – nuclear stations.

The accumulation of the energy is not a new idea in energetics. The fossil sources (petrol, coal, etc.) are effective accumulators with high density of energy. As a fact, of shortage of the traditional energy sources and increasing of their price it is necessary to reach other method for accumulation.

One of the methods is production and accumulation of renewable fuel. One variant is chemical accumulation. The energy could be stored in the chemical connection.

Hydrogen energy is one of the important directions in the developing of renewable energetics. The main priorities touch dissolving of problems connected with the use of hydrogen as a energy carries and accumulators.

The hydrogen could be derived using hydrolyze of a water and as a gas could be kept, transported and used for energy. The only residual product of burning of hydrogen is water, there is no environment pollution.

The storage of hydrogen in big quantities is not easy process, even using high pressures and this requires significant volumes [1-5, 8].

Gas hydrogen is stored in balloons (in high pressure) and transported via pipes from special materials with high prices.

The direct used of hydrogen as a gas could be realized using hydrating process. Thus it could be stored for a long time and to be used in the traditional engines. In the last years there are intensive works on creating new materials for hydrogen storage.

<table>
<thead>
<tr>
<th>Material</th>
<th>Composition</th>
<th>Working interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metals</td>
<td>Mg</td>
<td>300-400 atm.</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>0-200 atm.</td>
</tr>
<tr>
<td></td>
<td>Ti</td>
<td>500-600 atm.</td>
</tr>
<tr>
<td>Alloys</td>
<td>Mg-Ni</td>
<td>250-400 atm.</td>
</tr>
<tr>
<td></td>
<td>V-Cr-Mn</td>
<td>0-200 atm.</td>
</tr>
<tr>
<td></td>
<td>Ti-Al-Ni</td>
<td>200-600 atm.</td>
</tr>
</tbody>
</table>

When store the hydrogen in a type of a hydride the volume of the systems decreases about three times compared with the volume of the balloon, transportation simplification and no expenses for liquefaction.

The best materials for use are low temperatures (working temperature: -20÷100 °C) hydride of intermetallic compounds as a type AB5 (A–La, Ce; B–Ni, Co, Fe, Cu, Mn, Al), AB2 (A–Ti, Zr; B–Mn, Cr, Fe, V), AB (A–Ti, Zr, B–Fe, Co) and compounds based on Vanadium which have high volume concentration of hydrogen, but not sufficient capacity as a mass (less than 3% mass.).

In Table I the data for same perspective materials are shown [6].

The base advantages of metal hydride systems are high volume density of hydrogen, good interval of working pressure and temperatures, possibility for regulation of pressure and speed of hydrogen derivation, high purity and etc.
Including in the energy system of hydrogen accumulators of energy (complex of electrolizer of water, contained for hydrogen and oxygen and accumulator for fuel cell) appears to be useful (Fig. 1).

Such technical decision will insure creating of equipment for long time keeping of energy practically without losses. This leads to additional decreasing of system price.

Using of fuel cells in energy systems increase working capability.

The fuel cells have low toxic, low noise, variety of fuel wide interval of power (Fig. 2).

Still now the price of the energy is very high and relative low resource. The best resource, have polymer materials as PEM FC - 2÷5000 h work.

The accumulating of energy with the use of hydrogen can be realized in energy system with renewable sources (wind, sun, hydro energy).

The technology for hydrogen production from primary sources includes the use of electrolyzing equipment[]. The main work of such type systems is converting of electrical energy from renewable sources into chemical energy of hydrogen.

This energy can be used as a type of electrical or thermal energy depending on the need of the user.

The base element of the accumulating system is the equipment for hydrogen production. It is connected principally with the power of the renewable energy sources.

The use of the system electrolizer – fuel cell gives the possibility to realize significant accumulating effect.

The problem in RES is the fact, that energy production depends on the meteorology conditions and it could not be planed.

The fuel cell (FC) is a electrochemical energy current source, in which the direct transforming of energy from fuel and oxide.

This process is a result of uninterrupted supply of fuel to the electrodes (Fig. 2).

In hydrogen fuel cell the distribution is as follows: hydrogen to anode, oxygen to cathode.

Fuel cell with proto reaction, rapidly reach to the maximum working power and they generate current with high density – 2A/cm².

They have high dynamic range – after turning on FC immediately come in the nominal power from several microwatts to hundred wats.

II. INVESTIGATION THE POSSIBILITIES FOR HYDROGEN PRODUCTION USING PV-ENERGY

1.1. Experimental equipment.

The investigation of the possibilities for accumulating an energy using system electrolizer – fuel cell was done in the laboratory of Faculty of computer science and engineering, Burgas Free University (BFU).
This laboratory has different equipment as follows:

- **PV-central** (Fig. 3), mounted in the roof of the university with six photovoltaic panels and total installed power 1428 Wp (6x238 Wp). The roof space gives the possibility 50 PV-panels to be installed. The central can work in two modes: as a direct sublayer of electricity for the needs of BFU building or for hydrogen production;

- **Meteostation - BFU-METEO**, system for monitoring the parameters of sun radiation, temperature, wind in real time [7].
  The system has possibilities for writing, storage and analyzing of data received from the sensors.
  The diagrams and graphs are used; file exportation of data for the concrete period of time is supported.

- **Electrolizer – model HYDROFILL-FCH-010** from the company “Horizon Fuel Cell Technologies”. It is polymer electrolyte fuel cell with reverse action [9-11].
  The produced hydrogen is kept in special reservoir–cylinders from alloy type AB2 for hydrogen absorption.
  Represent a group of AB2 alloys containing titanium, zirconium or hafnium as a base and a metal (nickel, chromium, vanadium) in the lattice structure. Has the ability to absorb hydrogen to form hydrides full and saturation. The internal pressure of fully loaded cartridge remains 30 Bar (435 pounds per square inch-PSI).
  The electrolizer is supplied from PV, then the system is fully autonomous.

- **Fuel cell, model H-12 (H-20) (FCS-B12)** from the company “Horizon Fuel Cell Technologies”.
  It is a module of fuel cells type PEM FC and includes thirteen serial connected single cells with total power 20 W [9].

### 1.2. Investigation the yield of hydrogen using electrical energy from PV central.

With the help of meteostation BSU-MS the experimental data for sun radiation for seven months were received (Table 2).

| TABLE II |
| MONTHLY VALUES OF SUN RADIATION |

<table>
<thead>
<tr>
<th>Sun radiation (kWh/m²)</th>
<th>BFU-MS</th>
<th>PVGIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>August</td>
<td>187,15</td>
<td>211,73</td>
</tr>
<tr>
<td>September</td>
<td>135,17</td>
<td>163,8</td>
</tr>
<tr>
<td>October</td>
<td>84,62</td>
<td>123,38</td>
</tr>
<tr>
<td>November</td>
<td>36,43</td>
<td>82,5</td>
</tr>
<tr>
<td>December</td>
<td>36,31</td>
<td>59,52</td>
</tr>
<tr>
<td>January</td>
<td>63,85</td>
<td>66,34</td>
</tr>
<tr>
<td>February</td>
<td>75,65</td>
<td>82,04</td>
</tr>
</tbody>
</table>

The data were compared with the information automated system PVGIS gives for a point with geographical coordinates of Burgas Free University.

On the base of received data for the intensity and duration of sun radiation in the time of investigated period the theoretical values of generated energy were determined.

On Fig. 4 the radiation data for chosen day with the biggest intensity (19 august) are shown.

| TABLE III |
| GENERATED ELECTRICAL ENERGY (kWh) PER MONTH |

<table>
<thead>
<tr>
<th>Month</th>
<th>Number of panels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>August</td>
<td>22,271</td>
</tr>
<tr>
<td>September</td>
<td>16,085</td>
</tr>
<tr>
<td>October</td>
<td>10,070</td>
</tr>
<tr>
<td>November</td>
<td>6,069</td>
</tr>
<tr>
<td>December</td>
<td>6,049</td>
</tr>
<tr>
<td>January</td>
<td>10,637</td>
</tr>
<tr>
<td>February</td>
<td>12,603</td>
</tr>
</tbody>
</table>

The quantity of the energy, which could be received from the panels was determined using Eq.1.

$$ W = \left( k \times P_e \times N \right) / 1000 $$

Where:
- $W$ – produced electrical energy (W/h);
- $k$ – coefficient reading the power losses as a result for photovoltaic heating, as well as and angle change of sun beams dropping onto the photovoltaic during
the day. For winter months the value is 0.7; for summer the value is 0.5;
- \( P_w \) – power of the panel;
- \( N \) – number of panels.

The choice of the electrolizer power is in connection with the quantity electrical energy produced for one hour from PV.

The data for hydrogen which can be produced with different number of panels for months with experimental data for sun radiation are shown on Fig. 5.

The accumulated hydrogen could be used for production of electrical energy with the help of FC.

Data for quantity electrical energy which can be received from the accumulated hydrogen are shown on Fig. 6.

### III. CONCLUSION

So proposed complex systems, is suitable for practical student (laboratory) classes.

It gives the possibility to follow and analyze a cycle of technological processes – production of electrical energy from renewable energy sources, accumulation and reverse converting in electrical.

The other advantage of the proposed system is the possibility the produced electrical energy to be used for the needs of university building.

Independently that the effectiveness of transformation hydrogen into electricity is not high, the received energy successfully could be used in emergency switch off of power supply – for supporting of servers, emergency light etc.

### REFERENCES


Abstract – This article discusses the nature of learning in PBL and examines the empirical evidence supporting it. This paper shares some relevant published evidence that active problem solving by learning teams contributes to critical thinking and effective team communications, which can be carried forward into professional roles in the workplace. The curiosity and inspiration that inspired this paper was a research question “How does facilitated problem-based learning benefit a team of distributed learners when collaborating on designing and producing a practical solution?”

Keywords – Project Based Learning, Self Directed Learning, Matlab Ford-Fulkerson algorithm, Heuristiclab.

I. INTRODUCTION

The old-school model of learning facts passively and reciting them out of context is no longer sufficient to prepare students to survive in today’s world. Solving highly complex problems requires students to have both fundamental skills and Digital Age skills.

This paper begins with the basic thoughts on Learning based on the Project, as part of the theory of learning from experience. To develop such attitudes and the theory, a long period of time was needed over which knowledge has been divided into theoretical and practical knowledge, with these two segments being integrated only in recent times. In this approach to learning, knowledge is considered to be the product of experience.

This approach is broadly applicable in scientific research where the emphasis is not placed on learning, but rather on problem solving and knowledge transfer between members of the research group. PBL is a big part of modern learning environments. It takes students on a cool journey of creativity, exploration, and real-world relevance.

Problem-based learning (PBL) is an instructional method in which students learn through facilitated problem solving. In PBL, student learning centers on a complex problem that does not have a single correct answer. Students work in collaborative groups to identify what they need to learn in order to solve a problem. They engage in Self-Directed Learning (SDL) and then apply their new knowledge to the problem and reflect on what they learned and the effectiveness of the strategies employed. Problem Based teaches students 21st century skills as well as content. These skills include communication and presentation skills, organization and time management skills, research and inquiry skills, self-assessment and reflection skills, and group participation and leadership skills. By bringing real-life context and technology to the curriculum through a Project-based Learning approach, students are encouraged to become independent workers, critical thinkers, and lifelong learners. If students learn to take responsibility for their own learning, they will develop in the way to work with others in their adult life. Project-based Learning is not just a way of learning, but a way of working together, Fig. 1.

For many students, the appeal of this learning style comes from the authenticity of the experience. Students take on the role and behavior of those working in a particular discipline. Whether they are making a documentary video about an environmental concern, designing a travel brochure to highlight sites of historical significance in their community, or developing a multimedia presentation about the pros and cons of building a shopping mall, students are engaged in real-world activities that have significance beyond the classroom.

The teacher acts to facilitate the learning process rather than to provide knowledge. Teachers who are used to traditional instructional methods know how to manage a classroom when they’re directing a lesson, supervising individual assignments, or leading a discussion. But managing the varied and more team-based, lively activities found in a project might seem daunting to teachers new to PBL.

Project-based Learning is a model for classroom activity that shifts away from the usual classroom practices of short, isolated, teacher-centred lessons. PBL learning activities are long-term, interdisciplinary, student-centred, and integrated with real-world issues and practices. It is a method that fosters abstract, intellectual tasks to explore complex issues. It
promotes understanding, which is true knowledge. In PBL, students explore, make judgments, interpret, and synthesise information in meaningful ways. It is more representative of how adults are asked to learn and demonstrate knowledge.

The goals of PBL include helping students develop:

1) flexible knowledge,
2) effective problem-solving skills,
3) SDL skills,
4) effective collaboration skills, and
5) intrinsic motivation.

II. **HOW TO IMPLEMENT PROJECT-BASED LEARNING?**

A basic and simple overview of the PBL Process is illustrated in Fig. 2, which starts with a buy-in decision that the PBL protocol will add value to a lesson agenda and ends with the problem being solved and documenting a lesson learned. A seen by the arrows, steps are looped until the results are satisfying.

Real PBL, by contrast, is deep, complex, rigorous, and integrated where each stakeholder in the school plays an important role. In implementing PBL, its fundamentals are fourfold:

- Create teams of three or more students to work on an in-depth project for three to eight weeks.
- Introduce a complex entry question that establishes a student’s need to know, and scaffold the project with activities and new information that deepens the work.
- Calendar the project through plans, drafts, timely benchmarks, and finally the team’s presentation to an outside panel of experts drawn from parents and the community.
- Provide timely assessments and/or feedback on the projects for content, oral and written communication, teamwork, critical thinking, and other important skills.

Characteristics on which project based learning is based are:

- It is desirable that the group is small, or heterogeneous, so that the advanced students can help less advanced students,
- Project is organized around topical issues that the teacher and students find important,
- Content topics are organized around problems, not about discipline,
- Students manage the process of learning. The group carried out field research, studying literature and the like.

The project sets the student in the center of attention, as well as the promotion of his creative talents and possibilities. The student has a maximally active role. When the student is intellectually and functionally active, then he is intellectually developed.

Students address the terms of reference used by the same mindset and the same procedures that are used in science. The project continues to develop the skills necessary in life and work of adults and in everyday life.

Scenario consists of several phases, Table I.
Reflection by students is a time of pause to decide to stay in the loop or to complete the exercise because enough is known, or the time has expired. Reflecting on the relationship between problem solving and learning is a critical component of PBL and is needed to support the construction of extensive and flexible knowledge (Salomon and Perkins, 1989). This reflection should help learners understand the relationship between their learning and problem-solving goals. Reflection helps students to relate their new knowledge to their prior understanding, mindfully abstract knowledge, and understand how their learning and problem-solving strategies might be reapplied.

Project-based learning offers a wide range of benefits to both students and teachers. A growing body of academic research supports the use of project-based learning in school to engage students, cut absenteeism, boost cooperative learning skills, and improve academic performance (George Lucas Educational Foundation, 2001). For students, benefits of project-based learning include:

- Increased attendance, growth in self-reliance, and improved attitudes toward learning (Thomas, 2000)

- Academic gains equal to or better than those generated by other models, with students involved in projects taking greater responsibility for their own learning than during more traditional classroom activities (Boaler, 1997; SRI, 2000)

- Opportunities to develop complex skills, such as higher-order thinking, problem-solving, collaborating, and communicating (SRI, 2000)

- Access to a broader range of learning opportunities in the classroom, providing a strategy for engaging culturally diverse learners (Railsback, 2002)

### III. Solving Problem of the Collaborative Groups

Collaborative problem-solving groups are a key feature of PBL. One assumption of PBL is that the small group structure helps distribute the cognitive load among the members of the group, taking advantage of group members’ distributed expertise by allowing the whole group to tackle problems that would normally be too difficult for each student alone. In PBL groups, the students often work together to construct collaborative explanations. Most PBL groups need some help to collaborate effectively.

To solve this problem we can use heuristic method and a modified Ford-Fulkerson algorithm. This algorithm we use to make workflow formation model of heterogeneous groups of students who are learning in a team. To make this possible, it is necessary to create a MATLAB mathematical model. In this model the heterogeneity refers to the characteristics of students. We have taken into account the following features that are easy to identify on the basis of surveys and preliminary results of students: interest in the subject, the performance of the studies (the average), motivation, attitude toward work in a group performance studies on matters related to the subject of learning, Table II.

In order to simplify each of these characteristics a range of values from 1 to 5 is defined where 1 means a low and 5 means a high grade. In this way, each student presents a feature vector whose value ratings from 1 to 5. For example, student S₁ can be represented as S₁ (5, 5, 5, 5, 5). Total student score on the basis of heterogeneity weights is simply the sum of the elements of the vector characteristics.

### Table II. Characteristics of Students

<table>
<thead>
<tr>
<th>Students Group</th>
<th>Interest for the Course</th>
<th>Average Score</th>
<th>Motivation</th>
<th>Attitude toward work in a Group</th>
<th>Matters related to the Subject of Learning</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>S₁</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>S₂</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>S₃</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3.4</td>
</tr>
<tr>
<td>S₄</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>S₅</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>3.2</td>
</tr>
<tr>
<td>S₆</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>2.5</td>
</tr>
<tr>
<td>S₇</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>4.6</td>
</tr>
</tbody>
</table>

Fig. 3 shows vector distribution of the students group:

![Fig 3. Vector characteristics for Students Group.](image-url)

In this case, the matrix of mutual links looks like:
In Matlab we introduce described connected links:

```matlab
cm = sparse([1 1 1 3 2 4 5 6 7],[4 6 7 5 4 6 1 2 6],[4 3 2 2 3 3 2 3 3],7,7)
```

And draw the diagram group, Fig. 4:

```matlab
h = view(biograph(cm,[],'ShowWeights','on'))
```

Fig 4. PBL action steps, integrated with course assessment.

Now we are introducing a measure of the quality of the heterogeneity of the group according to the following principle: if from group of \( N \) students we remove the best and worst student on the basis of characteristic vectors, the results of other students should be somewhere in the middle compared to these two "border" students. It can be shown that the following formula for quality and heterogeneity of the group \( i \) or \( G_{Hi} \), gives greater value as a group is more heterogeneous.

The measure of \( GH \) can be computed as follows. Let \( AD_i \) be the average of the maximum and the minimum student-score in the \( i \)-th group.

\[
AD_i = \frac{\max \text{score}(S_1, S_2, ..., S_n) + \min \text{score}(S_1, S_2, ..., S_n)}{2}
\]

The measure of goodness of heterogeneity is then defined as:

\[
GH_i = \frac{\max \text{score}(S_1, S_2, ..., S_n) - \min \text{score}(S_1, S_2, ..., S_n)}{1 + \sum_j |AD_i - \text{score}(S_{j\alpha})|}
\]

where \( S_1, S_2, ..., S_n \) are students who belong to the group \( i \), \( AD_i \) represents the mean of the results of the best and worst student of the group \( i \) and a sum of \( j \) is the index of student group, wherein the index does not take value of the best and the worst student. If only large values of \( GH \) were pursued, it would lead to forming groups with extremely high coefficient of heterogeneity and groups with extremely low coefficient so that the final formula includes a coefficient of variance \( CV \) and then suitable algorithm is used to perform optimization for this formula. The final formula looks like this:

\[
F = \omega_{GH}GH + \omega_{CV}CV
\]

where \( GH \) is the sum of \( G_{Hi} \) for all groups, and \( CV \) is the coefficient of variance that represents the ratio of the standard deviation and the arithmetic mean of the results of all students, and \( \omega \) represents the weight. The process of optimization of this formula with the help of a Heuristiclab boils down to the definition of external tool for evaluation of solutions that are in fact based on a predefined final formula. Since this is the iterative process of finding solutions, this function is called for with each iteration. Next, we can select a suitable algorithm to optimize and adjust its parameters. In the end, it is necessary to carry out simulations with the modification of parameters (input, the algorithm and the weight of the formula) to provide a better solution whereby the operation can be performed using a suitable graphic interface of this environment.

IV. CONCLUSION

Given the current state of research on Project-Based Learning, what can we conclude about the relative merits of PBL as a teaching and learning method? Research on PBL implementation is largely limited to research on project-based science administered by teachers with limited prior experience with PBL. There is some evidence that students have difficulties benefiting from self-directed situations, especially in complex projects. The effectiveness of PBL as an instructional method may depend, to a greater extent than we recognize, on the incorporation of a range of supports to help students learn how to learn. There is direct and indirect evidence, both from students and teachers, that PBL is a more popular method of instruction than traditional methods. Additionally, students and teachers both believe that PBL is beneficial and effective as an instructional method.

REFERENCES

Collaborative Learning in Higher and Secondary Education

Tania Vasileva¹, Stela Stefanova² and Vassiliy Tchoumatchenko³

Abstract – The paper considers introduction of collaborative learning approach in university and secondary school settings. Two case studies of re-designed compulsory courses to promote students’ knowledge work practices by following the trialogical design principles are presented. The results from pilots courses conducted in ASIC Design and Networking Technologies are also highlighted.

Keywords – Collaborative learning, Knowledge work practices, Computer cloud technologies.

I. INTRODUCTION

In an increasingly global economy, effective creation, use and dissemination of knowledge is the key to success. In order to manage changes in the society and in the work life, new types of competencies are needed, such as collaborative learning, cultural awareness, self-leadership and flexibility. Widespread pedagogical methods and practices do not usually support these new challenges because the focus is on content learning rather than on fostering higher-order knowledge work competencies [1]. Many educational analysts and industry representatives report that students leave higher education with underdeveloped abilities to collaborate, manage their work processes, use computers, or solve open-ended problems [2]. Current technology now offers many more possibilities for sharing, archiving, retrieving, combining and generating new knowledge. Particularly in secondary education, technology is used infrequently, only by some teachers and often for previously established teaching methods but not for transforming practices.

Rapid changes and demands of the knowledge society, acceleration of technology and networking challenge educational institutions to reconsider pedagogical practices to ensure that students acquire necessary future competencies during upper secondary and university education. New strategies are needed for introducing pedagogical models addressing the use of collaborative work and cloud information technology into the educational systems. Students need interdisciplinary, goal-oriented projects, where cross-fertilization between schools, higher education institutions and professional organizations is enabled.

II. COURSES RECONSTRUCTION

In order to promote the development of new competencies through education, specific design principles based on the trialogical approach were created for supporting the design of pedagogy [4].

The problem was how to re-design our courses to better promote students’ knowledge work competencies and how to implement the trialogical design principles in own teaching in order to increase motivation of students to learn, to enhance their professional competences and soft skills:

- Abilities to resolve complex problems;
- Better practical training (experience in using professional software and CAD tools);
- Working on multidisciplinary tasks, utilizing multiple knowledge sources;
- Abilities to work in group;
- Abilities to use modern computer technologies and environments;
- Networking.

In order to achieve these objectives and resolve problems a trialogical educational approach was introduced with using cloud computing technologies, up-to-date communication tools for student-teacher connection, continuous monitoring and assistance students’ activities. We decided to reconstruct the courses and to adapt design principles as summarized below:

DP1: Organizing activities around shared object - Collaborative development of a semester long project and, preparation of a shared report
- Activities: face to face meeting for the distribution of project tasks, defining and preliminary review of the tools used; getting students acquainted with the phases of the design cycle.
- Team organization: students are free to choose team partners.

DP2: Supporting integration of personal and collective agency and work
- ‘Coordinate the participants’ interests – team members to choose an appropriate project they want to develop and are interested in.

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• Motivate students to manage tasks distribution between team members, having respect to deadlines by giving each student the responsibility of being a team leader in turn. There are two strictly defined deadlines during the project cycle and performing tasks within given deadlines is one of the criteria for project evaluation.
• Combining participants’ own interests and shared project through assessment process – the quality of the shared project and the responsibilities concerning deadlines are evaluated with a higher grade.

DP3: Emphasizing development and creativity through knowledge transformations and reflection
• Support versatile use of various kinds of knowledge: theoretical or literary sources; practical examples and cases; pictures, models. Discuss problems student faced during collective work on the shared object.
• Reflect on collective practices and knowledge.
• Make students comment on each other’s work through the semester.
• Encourage students to independently and creatively initiate, lead and manage a development process.
• Require student to apply already obtained knowledge and skills in using professional CAD tools to resolve complex practical tasks.

DP4: Fostering long-term processes of knowledge advancement
• Continuous working process, iterative design process to improve circuit and system performance in order to fulfill technical specifications.
• Planning and start writing the documents, sharing the drafts, getting feedback from the teacher and other students, improving the project and project report, submitting relevant documents.
• The best final team projects and their shared reports are used during the course as good examples for other teams, as well as after the course by the students themselves or by others.

DP5: Promoting cross-fertilization of knowledge practices and artifacts across communities
• Students use professional tools for projects development. They are provided with professional work models and design flow cycle used in the software and electronic industry.
• Expert practices are modeled for students, via templates and tools.
• Students and teachers collaborate on solving a shared problem.
• Students use up-to-date cloud computing and communication tools for planning, organizing and writing shared reports.

DP6: Providing flexible tools for developing artifacts and practices
• Google Drive for collaborative authoring of the project reports, reviewing and commenting.
• Google calendar – to set deadlines and to monitor progress – assignments, intermediate stages reporting, deadline for submission of the project.
• For inter-team communications students can choose their preferred tools (chat, conferences, e-mail, forums).

• For student – teacher communications Google applications are used: Gmail, Calendar, Drive.
Applying these design principles during the last two years, several engineering courses were re-designed at the TU - Sofia and the Technology school “Electronic Systems” from traditional face-to-face to collaborative project oriented adopting and applying modern online learning platforms, cloud collaboration tools, and social software. In the next section are discussed two cases in which teachers promote students’ knowledge work competences at university and secondary school education.

III. ASIC DESIGN COURSE
The bachelor degree ASIC Design course was transformed to project oriented following trialogical design principles in order to give students opportunity to work collaboratively in group with clear role of each participant. The infrastructure for collaborative learning consists of public cloud based services, combined in a way that supports electronic design workflow (Fig. 1).

![Collaborative workspace](Fig.1. Collaborative workspace)

Working in small teams, the students are required to design a digital Application Specific Integrated Circuit (ASIC). The design workflow is based on HDL (Hardware Design Language) modelling, verification and synthesis. The main design artefacts (HDL models and test-benches) are text files; therefore we are able to borrow many tools and workflows from the software development community. Projects are hosted on GitHub [5] – one repository per project.

In parallel with the code development, the teams are required to create and maintain a Google Docs document which is one of the major deliverables. Initially the document contains the technical specifications of the design. Later on, the students have to add description of the implemented algorithms and architectures, argumentation of the tradeoffs made and the results from the simulation, synthesis and physical design.

Most of development takes place outside the regular classes. For their intra-team communication, the students are free to choose whatever tools they prefer (chat, conferencing, email). For student - teacher communications we decided to
use the Google tools. Students were encouraged to submit their questions as in-document comment or email.

Collective artefacts evolution is followed through GitHub Revision History and Google Docs Revision History (Fig.2). GitHub is optimized for hosting software projects. It provides a very detailed history of commits for each repository. In the majority of cases, the tools provided by GitHub are more than adequate for analyzing the evolution of the student’s projects.

The functionality offered by Google Docs with respect to exploring documents history is rather limited. At a file level, there is an Activity view, that provides a good overview of when and who created or modified a particular document. At document level, we have a Revision history, which shows a timeline of the changes, but no information about the scope of each change.

Fig. 2 Collaborative artefact evolution – Google Docs/Drive

An effort is made to follow the test driven development process - first create a test-bench then the model that makes all the tests pass. Students are aware that the comprehensive test coverage will be one of the primary project evaluation and scoring criteria. All tests-bench should be self-checking - i.e. no “manual evaluation” of the simulation results should be required to determine the correctness of the model.

Team members have a collaborator rights for the respective repositories, but they were asked not to commit directly. Each change had to be peer reviewed before it can be committed to the project repository. When a team member submits a change for code review, the project is automatically built and the tests are executed. Another team member shall perform a code review and either approve the change or return it to the submitter for rework. System allows the reviewer to attach comments to a source code file or a particular line inside the file (Fig. 3).

The pilots were conducted with fourth year bachelor students. Each team had to choose a project subject from a list provided by the teacher. Two project milestones were set – intermediate report and final report. Each class had a Google calendar with all relevant milestones and class schedules. Project development in such practice permits for self-selected time and place allocation of the participants and teachers.

IV. GLOBAL NETWORKS COURSE

This case is an example of introducing university type of education in secondary school. Instead of giving 12th grade students many separate or loosely connected tasks strictly developed by the teacher we provide them with a 31 weeks long project. All group activities are organized around shared objects – collaboratively development of common project, preparation of shared report, continuous working process, and final presentation in teams. Secondary school students have to perform collaborative network design (Fig.4). In addition to the collaborative project work, they were required to submit several individual homework assignments.

Guidance is provided through systematic instructions and group work rules. Assessment includes process and product assessments, and contribution evaluation of each participant to the collaborative project development.

Fig. 3 Peer review

Fig. 4 Collaborative network design

Collaborative workspace for network design is shown in Fig. 5. Successful project development requires continues working process with iterative network configuration, performing numerous analysis of the designed network to
refine the network parameters and characteristics, planning and writing the documentation, sharing the drafts, asking the teacher and other students for feedback, improving the project and project documentation, submitting respective report and presenting the obtained design and simulation results. All these require intensive use of modern communication tools - forums, blogs and social media for discussing problems. Students submit their questions as in-document comments, which are context related. Professor answers in the document. The discussion is part of the artefact (Fig.5).

Students are advised by specialists from the ICT industry. Industry professionals, teachers and students discuss and analyze collaborative experience. Already gained knowledge and skills are practiced in the laboratory to solve the tasks of the project by using dedicated networking equipment.

V. CONCLUSION

The paper considers two case studies for introduction of collaborative learning approach at university and secondary school education to promote knowledge work competencies by implementing the trialogical design principle. The courses were re-designed from traditional face-to-face to collaborative project oriented adopting and applying modern online learning platforms, cloud collaboration tools, and social software. Activities and environments used in the conducted pilots are discussed. In a whole, it has been a rewarding experience for both students and teachers. The trialogical approach was well accepted and considered as an appropriate path for transforming students’ individual work into more collaborative activities. Students consider their experience to work in teams as very positive, challenging and useful to understand the benefits of collaborative working. Together with learning subject matter they played (and learned) with new communication and collaborative technologies. The immediacy of the help provided via email and in-document, contextual comments, compared to the scheduled face to face meeting, was cited as a major plus in the post-courses surveys in both institutions – university and technology school.

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Laboratory stand for experiments in real time with applications in training on control non-linear systems

Veselin Nachev¹, Tanya Titova² and Plamen Nikovski³

Abstract – In the work are resumed theoretical and practical aspects in the study of oscillation in on nonlinear control systems. Addition to reviewing of analytical methods for determining the parameters of oscillation is described laboratory stand and methodology for carrying out the experimental research. The presented work in paper is applicable in the learning process of students in the course "Theory of automatic control", as is intended effect of stimulating the activity of students with the use of programming and physical model of object for control.

Keywords – nonlinear control, harmonic linearization, real time control, MATLAB instrumentation control

I. INTRODUCTION

Objectives of development: Designing and realizing laboratory stand for demonstration and training in automation that integrates two basic methods for synthesis and analysis of control systems - simulation modeling and physical modeling.

Application of laboratory stand: Computer-based learning of basic principles of control, setting regulators, synthesis of control algorithms, studying effects such as non-linearity, saturation, "wind-up", noise, factors with adverse influence, etc., inherent to real objects for automation. Examines is the method of harmonic linearization (describing function method).

Main advantages:
- Create a flexible environment, combining the advantages of simulation and physical modeling.
- Reducing the level of abstraction typical of simulation modeling.
- Opportunity for graphical visualization and data recording.
- Intensification of training related to the possibility of realization of a large number of experimental settings.

II. MATERIALS AND METHODS

In the literature there are a significant number of examples of the use of real-time control system in the automation training [1-3,6-8].

Oscillating behavior are typical of nonlinear systems. In these systems usually contain positional elements, such as controlling devices, secondary measuring means or actuators, which are characterized by simple realization, but reliability and low grade value. In most cases, non-linearity may be presented with straightforward types non-linearly characteristic - "dead zone", "saturation", positional elements and others. The auto-oscillations sufficiently objective is characterized by an amplitude (A) and frequency of oscillations (ω_o). The value of A determines the accuracy of the regulation process and the frequency characterizes the intensity of the switching actuator. By considerations of reliability of the actuator in the synthesis of the system ω_o is minimized. In many cases also, the parameters of oscillation allow to define the conditions for the stability of the system. The most common method for the study of oscillations of non-linear systems is the method of harmonic linearization. The essence of the method is presented in the following steps.

1. Decoupled non-linear feedback system. It is necessary the transformation of the structural scheme of the system, so that the one summarized non-linear element and the remainder a linear unit (Figure 1).

2. Verification of the hypothesis of low-pass filter of the linear part. Perform a amplitude-frequency response of the linear part. Let there be the kind shown in Figure 2.

In the transformation is not allowed:
- exchange of linear element with non-linear and conversely (without time delay). This is necessitated by the invalidity of the principle of commutative property.
- moving the non-linear unit through summing node. It is necessary failure to of the principle of superposition.

2. Verification of the hypothesis of low-pass filter of the linear part.

Perform a amplitude-frequency response of the linear part. Let there be the kind shown in Figure 2.
If \( \omega^* \) is the frequency of the first harmonic (fundamental frequency) of oscillation, higher harmonic multiples of it with \( 2\omega^*, 3\omega^*, \dotsc \) hypothesis for low-pass filter is confirmed in the case of satisfying the condition
\[
| W_L(j\omega^*) | >> | W_i(jn\omega^*) |, \quad n = 2, 3, \dotsc
\]

3. Obtaining coefficient on harmonic linearization.

This is for structural scheme of the type at Fig.1. The linear part has the form (in autonomous system \( U_p = 0 \)):
\[
y = K_L(s)z,
\]

When an oscillator process (if \( y \) is harmonic oscillation), passing through the non-linear element signal remains periodic not strictly harmonious, but with the same period and may be decomposed in order for Fourier harmonics with frequency components at integer multiples \( n\omega^* \). Moreover, suppose that the linear dynamic system is a filter of low frequencies and missed only the first (hypothesis filter). If this assumption is not performing, errors of the method of harmonic linearization may be significant.

Let
\[
z = F(y); \quad y = A \sin \alpha x.
\]

We present \( z \) in the order of Fourier:
\[
z = C_0 + D_1 \sin \alpha x + C_1 \cos \alpha x + D_2 \sin 2\alpha x + \ldots
\]
\[
(1)
\]

In symmetric non-linearity \( F(-y) = -F(y) \) is applied:
\[
C_0 = \frac{1}{2\pi} \int_0^{2\pi} F(A \sin \alpha x) dx(A\alpha x) = 0.
\]

When filtering harmonics of high order is necessary to determine only the coefficients \( D_1 \) and \( C_1 \) in equation (1).

After a substitution:
\[
z = F(y) = F(A \sin \alpha x) = D_1 \sin \alpha x + C_1 \cos \alpha x =
\]
\[
= D_1 \sin \alpha x + C_1 \frac{d}{dt} \sin \alpha x =
\]
\[
= \left( D_1 \sin \alpha x + \frac{C_1}{\omega} \sin \alpha x \right) \frac{A}{A} = \left( \frac{D_1}{A} + \frac{C_1}{A \omega} \right) A \sin \alpha x
\]

As a result, we obtain the equivalent transfer function of the non-linear element:
\[
W_{NE} = \frac{F(A \sin \alpha x)}{A \sin \alpha x} = \frac{D_1}{A} + \frac{C_1}{A \omega} s = q_0 + q_1 \frac{s}{A \omega} \quad (2)
\]

or \( \z = q_0 Y + q_1 \frac{Sy}{A \omega} \)

where:
\[
q_0 = \frac{D_1}{A} = \frac{1}{\pi A} \int_0^{2\pi} F(A \sin \phi) \sin \phi \cdot d\phi,
\]
\[
q_1 = \frac{C_1}{A} = \frac{1}{\pi A} \int_0^{2\pi} F(A \sin \phi) \cos \phi \cdot d\phi.
\]

Thus the non-linear equation for \( z \) is replaced by the approximate equation (2) for the first harmonic. The coefficients \( q_0 \) and \( q_1 \) are called coefficient of harmonic linearization. They may depend on the amplitude and the frequency.

Displayed linearization coefficients for typical nonlinearities can be found in reference [4]. For the non-typical should be derived from (3).

4. Analysis.

The most commonly used methods for analyzing the method of harmonic linearization are [4]:
- Determining the parameters of oscillation using the criterion of Routh–Hurwitz.
- Determining the parameters of oscillation and stability using the criterion of Mihaylov.

III. LABORATORY EXPERIMENTS

The principal scheme of laboratory stand which is realized is presented in Figure 3.
Figure 4 shows the existing model.

The physical model communicates with the computer system and software, by means of a device for data collection (Data Acquisition, DAQ) - NI USB-6008 devices mainly include analog-to-digital (A/D) and digital-to-analog (D/A) converters, which are generally known as data converters.

Figure 5 shows scheme realizing the function of the control device, in this case PID - regulator, which performed the necessary simulations and analyzes in the middle of MATLAB / SIMULINK. In particular - setting the parameters of the regulator.

Training example: a system of third order with two-position relay.

1. Object

\[
G = \frac{21.6}{e^{-4s}(s^3 + 108s^2 + 147s + 1)}
\]

Transfer function:

\[
\frac{21.6}{s^3 + 108s^2 + 147s + 1}
\]

2. Non-linear element - two-position polarized relay with hysteresis:

\[
Z = \frac{-1}{W_{non}}
\]

3. Receive coefficients of harmonic linearization.

\[
A = 1:0.0001:20;
W_{non} = ((4*5)/(pi.*A)).*sqrt(1-(1./((A.^2)./(A.^2))))
\]

4. Plotting Nyquist on the linear part and Goldfarb \((-1/W_{ne}(A))\).

5. Defining the parameters of oscillation in the intersection point on hodographs.

6. Plotting model in Simulink, confirm the results of the presence of oscillator regime and evaluation of error for linearization.

Other schemes (tasks or "scenarios") that are made with laboratory stand are:
- Removing the transfer function on input and disturbance;
- Determination of the inertness on sensor;
- Definition of quality parameters of step response;
- Setting the controller on defined criteria of quality of step response;
- Control with two-position controller;
- Control with three-position controller;
- Synthesis of logical algorithms such as "if-then" eliminate the effects wind-up;
- Design of advanced control algorithms - neural, fuzzy, adaptive robust systems;
- Filtering, normalization and calibration signals from sensors, etc.

Fig. 10. Example simulation scheme for control of the object with PID and actuator saturation.

IV. CONCLUSION

The idea presented development is led from the need to implement innovative training methods - practical training in close to industrial environments, training base project development, problem-based learning and more. In this case this was achieved using a real physical object in combination with virtual tools for its control.

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Using PLC for Control on Asynchronous Drives – Laboratory Simulator

Vasil Dimitrov¹ and Emiliya Dimitrova²

Abstract – In this paper some laboratory stands that offer opportunities for various asynchronous drives testing are described. A PLC has been involved into simulators for monitoring and control on the drive performance. A touch panel, connected to the PLC, gives a possibility of entering data of initialization and operation conditions. The simulators are useful in the students training and research.

Keywords – asynchronous drive, soft starter, programmable logic controller (PLC).

I. INTRODUCTION

Programmable Logic Controllers (PLCs) are often used in the contemporary SCADA-systems and in many industrial sectors. PLCs are computer-based solid-state devices that control industrial equipment and processes. They have a user-programmable memory for storing instructions for the purpose of implementing specific functions such as I/O control, logic, timing, counting, three mode proportional-integral-derivative (PID) control, communication, arithmetic, and data and file processing. PLCs are used extensively in almost all industrial processes as the primary components in smaller control system configurations and provide operational control of discrete processes. PLCs are also used to accomplish the desired product and/or process tolerance around a specified set point. Then they can be employed in the control on localized processes and proportional, integral, and/or derivative settings on the PLC to be tuned to provide the desired tolerance as well as the rate of self-correction during process upsets (PID control). In SCADA systems, PLCs are often used at the field level as process controllers and RTUs because they are more economical, versatile, flexible, and configurable than special-purpose RTUs [1, 2, 6].

On the other hand, the fast industrial progress set up higher requirements of education quality. The training under the bachelor and master programmes in the Todor Kableshkov University of Transport prepares highly qualified experts in the fields of the Electrical Equipment of the transport, industry and power engineering. Training the skills for involving, programming, and setting-up the PLCs and human-machine interface is very important. Knowledge of the relevant software products is necessary. Evaluation of the PLC’s possibilities for its using in different power drive systems for efficiency optimization is also very important.

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II. LABORATORY SIMULATORS FOR ASYNCHRONOUS DRIVES EXAMINATIONS

The fast development of electrical drives and control systems has set up higher requirements to research and education quality. Several laboratory simulators have been designed and built on contemporary devices. They offer various opportunities to examine different asynchronous drives at inconstant load torque.

A. Laboratory Simulators for testing of Frequency Controlled Asynchronous Drives

The main elements involved in the configuration of one of the simulators are developed by Siemens (Fig. 1): three phase energy-saving asynchronous motor with lightweight construction (AM – 2.2 kW, 1440 rpm); Sinamics G120 frequency converter; Simatic S7-200 Programmable Logic Controller (PLC); TP-177micro Touch Panel. A synchronous generator (SG – 30V, 60A) and variable resistor R simulate the load of the motor. Three sensors are mounted on the load system. They are connected to the PLC and form the system for assessing of the torque. The Differential Amplifier DA1 is used as voltage sensor. The current transducer HAS100S is a Hall Effect sensor measuring the generator current Ig. Its output voltage is amplified by DA2. A rotary encoder reports the generator speed ng [2]. There is also a positioning system.

TP 177micro Touch panel connected to the PLC gives the possibility of monitoring and control on the drive system as well as of entering the initialization and parameterization data and work conditions.

A Windows-based computer system is used for configuring and data storage. The necessary commissioning software Starter is installed on this computer and is used for setting-up the Sinamics G120. A subprogram Trace is used for real-time tracing the inverter parameters. This is a great opportunity of an experimental research of transient modes of the frequency controlled asynchronous drives [3].

The simulator offers various possibilities of examination on a frequency controlled asynchronous drive at inconstant load torque. The influence of parameters and operating modes of the inverter on the energetic drive performance could be examined [2,3]. Using the subprogram Trace, the dynamic characteristics with starting, stopping and changing the load or the speed set point could be captured. All data are exported to Excel tables and graphs can be automatically plotted. Transient modes have a big practical importance, since the correct choice of motor power, the proper selection and sizing of the apparatus of control system, the reduction of energy consumption during starting and stopping are based on them.
The existence of a PLC and touch panel TP177Micro allows for simultaneous drive control and parameters tracing and capturing. Simatic S7-200 can be used for control and optimization tasks both for the inverter drive and the positioning system. A linear encoder reports the travelled distance of the positioning axis to the S7-200. A rotary encoder is used for closed loop speed control on the drive. A possibility of torque evaluation is created and optimal drive behaviour could be achieved. Adaptive control can be implemented. It is used when the automatic control drive system has to modify its own characteristics, depending on the operating conditions, i.e. the automatic control system adjusts (adapts) itself to variations in environment. Such control is embedded in many contemporary positioning systems. The requirements for operation with high precision, ensured and sustainable in all ranges of operating speeds, are achieved through control on the positioning, speed and torque of the motors. Adaptive control on a traction asynchronous drive could be also simulated - indirect identification of disturbances could be realized. It takes into consideration the change of controlled parameters as a result of a disturbance.

Another simulator is based on a single phase frequency converter ELDI developed by the Bulgarian company Electroinvent Ltd (Fig. 2). The load torque can be changed by regulation of the flux of a synchronous generator. The influence of parameters and operating modes of the inverter on the energetic drive performance can be examined using the network analyzer Net Vision 2010. The true RMS values of the voltage and current are measured simultaneously. Active power, reactive power, power factor, sequence of rotation, harmonic analysis are computed and indicated. The vector diagram and the waveforms of the input signals can also be drawn on the graphic LCD display [4].

B. Laboratory Simulators for testing of a directly plugged in the grid Asynchronous Drive at inconstant load torque

The laboratory stand for asynchronous drive examinations is shown in Fig. 3. This motor is made in Bulgaria; its power is 3 kW. A load of the motor can be changed by an electromagnetic brake (EMC). Possibility of reverse is provided. The necessary locks and protection and control equipment are also assured. Methods for laboratory examinations and tests by instrumentation with high accuracy are developed: determination of the static mechanical and electromechanical characteristics and characteristics that show the change of energetic parameters (power factor, efficiency, THD etc.) of the drive at the load change [5].

III. UPGRADING THE LABORATORY SIMULATOR

The speed regulation of the asynchronous motors in many fields of industry is not necessary. Many drives need to be started and stopped smoothly but its speed has to be constant through the operating modes. Intelligent devices called “Soft starters” can be used in those cases.

A motor soft starter is a device used with AC induction motors to temporarily reduce the torque and current surge during start-up. This reduces the mechanical stress on the motor and shaft, as well as the electrodynamic stresses on the
electrical distribution network, extending the lifespan of the system [7]. Electrical soft starters reduce the torque by temporal reduction of the voltage or current input. Typically, the voltage is controlled by reverse-parallel-connected thyristors. The soft starter continuously controls the three-phase motor’s voltage supply during the start-up phase. This way, the motor is adjusted to the machine’s load behavior. Mechanical operating equipment is accelerated smoothly. Service life, operating behavior and work flows are positively influenced. The thyristors can be bypassed by a relay or a contactor in steady-state operation. Electrical soft starters can use solid state devices to control the current flow and therefore the voltage applied to the motor. They can be connected in series with the line voltage applied to the motor, or can be connected inside the delta (Δ) loop of a delta-connected motor, controlling the voltage applied to each winding. Solid state soft starters can control one or more phases of the voltage applied to the induction motor with the best results achieved by three-phase control.

Soft starters can be set up to the requirements of the individual application. In pump applications, a soft start can avoid pressure surges. Conveyor belt systems can be smoothly started, avoiding jerk and stress on drive components. Fans or other systems with belt drives can be started slowly to avoid belt slipping. Soft starts are seen in electrical R/C helicopters, and allow the rotor blades to spool-up in a smooth, controlled manner rather than a sudden surge. In all systems, a soft start limits the inrush current and so improves stability of the power supply and reduces transient voltage drops that may affect other loads.

Therefore, the study and examination of the soft starters is very important. The laboratory stand shown in Fig. 3 can be upgraded with an appropriate soft starter. Altistart 01 soft start/soft stop units ATS01N2 developed by Schneider Electric Company could be used [7].

The Altistart 01 starters enhance the starting performance of asynchronous motors by allowing them to start gradually, smoothly, and in a controlled manner. It helps to prevent mechanical shocks, which cause wear and tear, and subsequent maintenance work and production downtime. The series includes several devices offering various features. Some of them operate only as a torque limiter on starting, but others can be used as a soft start/soft stop unit for asynchronous motors.

The Altistart U01 limits the starting torque and current peaks on starting on machines that do not require a high starting torque. It is designed for the following simple applications: conveyors, compressors, conveyor belts, pumps,
fans, automatic doors and gates, small cranes, belt-driven machinery, etc.

The Altistart 01 ATS01N1 soft starters control one phase of the motor power supply (single-phase or three-phase) to limit the starting torque. They feature an internal bypass relay. An external power supply is required for controlling the starter. A contactor is always required to shut off power to the motor.

The Altistart 01 ATS01N2 soft start/soft stop units control two phases of the motor power supply to limit the starting current and for deceleration. They also feature an internal bypass relay. The use of a line contactor is not necessary on machines where electrical isolation is not required. These devices are equipped with 3 potentiometers for setting the starting and deceleration time and for adjusting the starting voltage threshold according to the motor load. 2 logic inputs provide Run/Stop commands and 1 logic input can be used for the Boost function. 1 logic output indicates the end of starting and 1 relay output indicates that the motor has reached a standstill at the end of the deceleration stage. These inputs and outputs can be connected to the PLC Simatic S7-200. The scheme of the upgraded simulator is shown in Fig. 4. The line circuit breaker is mounted between the grid and soft starter, but is not shown in scheme. TP177micro Touch Panel can be configured for Start / Stop and Boost commands, which can be transmitted through the PLC to the soft starter. Digital inputs of the PLC can be used for receiving the information about drive condition.

![Diagram of Altistart 01 ATS01N2 Soft Starter with PLC and Touch Panel](image)

**Fig. 4. Simulator for testing of an asynchronous drive with soft starter**

**IV. CONCLUSION**

Soft starters are widely used in industry for control on asynchronous drives when the speed regulation is not a mandatory requirement. They are cheaper than inverters and frequency converters and allow temporal reduction of the torque and current surge during start-up, as well as smooth deceleration.

PLCs are often implemented as primary components in small and medium control system configurations. The PLC Simatic S7-200 offers maximum automation at minimum cost. It is compact, fast and highly powerful, feature great communications capabilities and it is based on very user-friendly software and hardware. It can be used for complex automation tasks and finds application in many branches of industry, power engineering and transport.

These advantages cause to teaching the students how to use and program soft starters and PLCs. The upgraded simulator offers various possibilities of implementation into practice many laboratory exercises, for example:

- Examination of an asynchronous motor at a constant speed and variable load;
- Study of the influence of the start-up and ramp-down time on the drive performance.

The laboratory simulator gives possibilities of student’s practical training in many terms of reference, for example:

- Training the programming skills for setting-up the soft starters, PLCs and touch screens – a knowledge of the relevant software products is necessary;
- Synthesis of algorithms for optimal control on the drive systems;
- Evaluation of the PLC’s possibilities of its using in the drive systems for the efficiency optimization.

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Importance of Learning to Code, Coding to Learn in Higher Education
Anton J. Knierzinger¹ and Boyka Gradinarova²

Abstract – Computer and internet give essential features to our life. Should all students learn programming? The message of this paper is a plea to improve the quality of highest education via bringing forward the importance of algorithms by stating their role in different sectors of our society as well as the learning and teaching process. Algorithmic thinking should be part of all subjects at all levels of education, because it improves the chances of our students in many directions and reflects the responsibility of education for our society. But coding in that sense is different from traditional programming. Teaching coding has three aspects:

- a technical approach - what are we talking about
- a social approach - why are we talking about
- a didactic approach - how are we talking about.

Keywords – algorithm, digital society, coding, programming, education.

I. INTRODUCTION

Let us spring from data. We commonly understand data as information, values or findings, which has been discovered by measurement or observation. Data are object of political discussion in form of data protection or data security. We affiliate their possession with economic power.

A definition of an algorithms by Wikipedia is „a self-contained step-by-step set of operations to be performed” either in real life or virtually on a computer. „Algorithms exist that perform calculation, data processing, and automated reasoning”

Anyway algorithms are proposed actions. They occur everywhere in our life, cooking recipes, instructions for technical installations, turn-by-turn directions for a route, there are many other examples. So we all have internalized the concept of an algorithms. By defining them we structure a problem into pieces and doing so we prepare it to be operated in a machine.

Teaching algorithmic thinking conveys two important competences:

- problem analysis and
- problem solving.

Their importance for our life, for science, society and education is commonly underestimated. Algorithms allocate power and distribute chances. Especially because of that we propose that the preoccupation with this topic should be part of education at all age level.

Where in society do we meet algorithms. We identified four major areas, all of them with great influence on our life.

1. Science and technology They have a great relevance in IT studies. But there are numerous examples in many other disciplines where algorithms play an important role.

2. Society and economy Algorithms and their ownership provide clout and power in our society, but they also offer creativity and fun, they facilitate advancement and value.

3. Pedagogy and human development In general (full development of the human being via education) and in vocational training (the imparting and acquisition of specific skills) teaching algorithmic thinking and the knowledge how to deal with coding improves the chances of our students in different ways.

4. Didactics and education Using coding as a principle of teaching improves education by offering new ways of creativity, connection to real life and allow to have fun via learning. It is our experience since the introduction of IT into education that this can intensively change and improve the process of teaching and learning.

II. SCIENCE AND TECHNOLOGY

Paradigmatically we want to have a look on different areas where coding is playing a major role in science and technology.

A. Automatisation

Industry 4.0 is defined as the „informatization” of production technology and logistics by machine-to machine communication. It is also named as smart or networked production. Within industry 4.0 robots can take a lot of hard work from the shoulders of their human companions. They work on the basis of cyber-physical systems and what is called the internet of things.

But automatization will reach nearly all areas of our life. That leads to the question: Are we in danger to loose our jobs to a robot? BBC has published a web-site „Will a robot take your job?” based on a study done by Oxford University and Deloitte (http://www.bbc.com/news/technology-34066941). Oxford University academics Michael Osborne and Carl Frey calculated how susceptible to automation each job is based on nine key skills required to perform it; social perceptiveness, negotiation, persuasion, assisting and caring for others, originality, fine arts, finger, manual dexterity and the need to work in a cramped work space. Students can investigate the future chances of their profession and find amazing facts.

B. Robotics

Undoubtedly their are numerous fields for the use of robots. It can be inspiring and informative to present them in lesson.

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Robots are fundamental of modern military strategies. We find them as drones, secret agents, fighters and helpers for soldiers. Associated with the technology we have to rise questions like:

- Is the inhibition threshold dropping?
- Who then decides on life or death?
- Will less or more people killed in an electronic war?

But robots will play other different roles in the future. They will act as servants, tour guides, play mates for kids, aid worker, lawnmowers and toys. At it we should discuss the following questions with our students:

- Under what conditions should robots replace humans?
- Can robots have human qualities like creativity, real emotion and spontaneity?

We have to discuss what Joseph Weizenbaum [3], famous for ELIZA, the first algorithm with human behavior, turned during the last years into an „old any man” asking: Are we in danger that when robots simulate man, humans are more an more simulating robots? Robots touch very much our self-conception.

C. Autonomous Transportation Systems

Autonomous logistics describes systems that offer unmanned, autonomous transfer of equipment, baggage, people, information or resources from one point to another without human intervention. This is a new area for research and development and therefor of great interest for higher education.

Visualization and coding of processes plays an ever-growing role in our society and therefor represent an emerging market. Examples are image editing, the revolution of music industry caused by the invention of the MP3 algorithm or the development of the digital presentation technique. An example of future trends in visualization can be seen in an advertisement for the upcoming video product HoloLens (www.microsoft.com/microsoft-hololens/en-us?video-url=vdeHHP). Microsoft HoloLens is the first fully untethered, holographic computer, enabling high-definition holograms to integrate with your world. It offers the possibility to combine real and virtual objects to one perceived reality. A sentence quoted from Microsoft describes the impact of visualization: „If you can change the way you see the world, you can change the world you see!“ According to Marshall McLuhan a change in media technology implicates a didactic commission for higher education.

D. Meteorology

Meteorology is one of only two more examples of natural sciences that we show, where algorithms are involved in the process during the last decades. The success in the prediction of weather is mainly depending on the speed of the computer systems and the quality of the algorithms used. The improvement of both factors made it possible to increase the complexity of the models for computation.

IT is also used for the fast processing of the big amount of data produced by weather satellites, the prediction of natural disasters and the online visualization of weather forecasts.

E. Biology

The importance of algorithms in biology is usually underestimated. Without adequate algorithms the decoding of the human genome would not have been possible in a short time. This has big influence in medicine, pharmacology, agriculture and forensic examination. But also IT is learning from biology. In artificial intelligence, an evolutionary algorithm (EA) is defined as a generic population-based optimization algorithm. It uses mechanisms inspired by biological evolution, such as reproduction and selection. Bionics is the use of methods taken from biological systems to the design of modern technology. In robotics the study of bionics has produced efficient designs for robots, artificial neurons, artificial neural networks and swarm intelligence. Algorithms are used for the simulation of biochemical processes and in the workflow management of clinical research. Therefore a lot of European universities offer special studies in bionics. They can be seen as an example for the improvement of higher education by an interdisciplinary approach.

III. SOCIETY

There are many samples how algorithms influence our society and sequent our life. For illustration it is enough to demonstrate three of them.

A. Politics

The participation of citizens in political decisions is based on the following mechanisms in the political process:

- Elections

It has been a long debate in Europe to what extent voting can and should be maintained by IT. But the fundament of free elections is the trust of the participating citizens in the system used to collect the votes. As people are always confronted with the misuse of their data in Austria there is no electronic voting at the moment. In Bulgaria there is a living public discussion on electronic voting.

Grassroots democracy

At the end IT supported ways of collecting the public opinion could lead to a stronger civic involvement. But the attempts of the Pirates Party to foster civic participation in Germany using a software called „Liquid Democracy” shows that there are limits and their violation obstruct the political process and the contribution of a political movement, because sometimes it takes much time to come to an end.

- Open data and open codes

We need ways how responsible citizens come to the information which they need for participation. In the EU we see an ongoing debate on how the access to governmental data should be organized. The majority of the algorithms we are subject to is not in possession of governments but in the hand of a few global players in IT industry. We propose a discussion of their role and how the rights of the people on data and the algorithms used for their processing can be saved.

- Communication

For example the political processes in northern Africa in the last years have shown the importance of open communication for a progress in society.
Among the various possibilities of the use of algorithms in economy we want to present only two but very characteristic examples:

- User profiling
  User profiling is used in different ways. On example is individually designed advertising. To do this you have to collect data about your clients, but the main factor for success is an algorithm for a suitable analysis. The most extreme use of client profiling we found in Switzerland. COOP tried individual pricing. The price of a specific good was not only determined by time and the location of the shop but also by the analysis of the buying behavior of the client detected by clandestine algorithms. This project has been terminated because it caused a storm of protest.

- Share market
  A considerable part of the trading of shares is currently done by algorithms. This led to a competition concerning the quality of the algorithms used between the major players in stock market. The quality of the codes used has a big influence on the performance of trading companies. The CEO of an Austrian bank told us that he prefers mathematicians instead of economists in his treasury department.

The influence of algorithms on arts is widely unknown, but there are interesting and numerous examples for the use of algorithms to generate artistic expression. Artists use algorithms since ancient times. For example you will find them by Leonardo da Vinci, Bach, Mozart, and Escher. Beside visual design algorithms are also used for computer generated music and poetry today.

Linz in Austria has a special and worldwide know center for electronic art, the AEC - Ars Electronica Center. It's FutureLab is a place for researching and trying out new cyberarts technologies. Once a year, Ars Electronica invites artists, scientists and researchers from all over the world to a conclave in Linz to confront a specific, interdisciplinary theme in the context of speeches, workshops, exhibitions and symposia. A yearly competition called u19 is dealing with questions like: Who decides, how the next generation will be determined by time and the location of the shop but also by the analysis of the buying behavior of the client detected by clandestine algorithms. This project has been terminated because it caused a storm of protest.

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20 years? Which technologies will be used then? How is our society developing? Which artistic ideas can help us?

IV. PEDAGOGY AND HUMAN DEVELOPMENT

Beside all the societal, economic, creative or somehow other good reasons to talk about algorithms in university courses, there is one, and we think to is probably the most important for teachers, „Dealing with algorithms in education increases the chances in life of our students.”. And we can see this in various directions.

This affects at least four areas of competences: According to our experiences during the last decades and proven by many studies, teaching coding and algorithmic thinking leads to an enhancement of the competences of our students.

This affects at least four areas of competences:

Professional Competences:
- cognitive competences, because they learn how a decision as a structure of choice have an influence on an algorithm
- analytic competences, because for the solution of a problem they have to isolate, analyze and structure the necessary information
- logical reasoning and faculty of abstraction
- problem solving • selection and application of suitable tools

Methodological competences

Students gain abilities in the use of IT-methods, the usage of digital media, acquisition of information and their evaluation and visualization.

Occupational outlook

The preoccupation with coding, the work on computers and the general competences in problem solving lead to proficiencies far wider than traditional IT-training. The excogitated dealing with algorithms in university courses lead to

- a widening of the spectrum of professions seen as possible and / or worthwhile
- improves the chances on the labor market. Students gain abilities in the use of IT-methods, the usage of digital media, acquisition of information and their evaluation and visualization.

Personal Competences

Beyond doubt we could observe an alteration and enhancement of the personal competences of our students and the kids participating in the computer camps in Bulgaria touches especially their self-confidence and the self-assessment of their own prospects [3].

The better and proper handling of digital media facilitates the most important competences in job and life in general. This can be demonstrated by the findings in the evaluation study of the „Power Girls Project 2013” in Upper Austria done by Alfred Weinberger from University of Education Linz. Power Girl is an initiative of Education Group, a governmental agency aiming the integration of media and technology in schools. The results of the yearly evaluations since 2008 show clearly the positive effects of the engagement in technology of girls on occupational and personal competences.

Girls who participate in the „Power Girls Project” boast
- a more emancipated and stronger non-traditional role model,
- value their own technical competences higher,
- are more interested in technical-oriented jobs and qualifications and
- choose more often higher technical education (schools, apprenticeships) than girls not taking part in this project.

V. DIDACTICS

When we started to integrate IT into education at the beginning of the eighties of the last century, we could feel that we had received a medium for revolutionizing didactics at
school and university level. But during the years we unfortunately lost our feeling for this mission and a concept of IT as a medium for better employment gained ground. There are several reasons for that and it is worth to discuss them in order to redesign the whole process.

We see that
• IT lost its special position
• persistence of the education system • a wrong selection of content

There are two main reasons why Informatics lost a large portion of her attractiveness and the number of beginners in IT studies in Germany and Austria is declining in the last years.

1. The abnegation of core topics of IT, like programming, and the concentration on application software might accommodate the interests of economists. But this doesn’t fit to the expectations of our students. They want to work creatively and choose their tools by themselves.

2. We do not pay enough respect to McLuhan’s subtext „The medium is the message“. The message of coding is that it needs its own didactics. When observed this can lead to fantastic results.

To support this view we want to show a model for creative learning presented by Mitchel Resnick. He was working with Seymour Papert and is the developer of the educational programming language LOGO. Resnick proposed a model with four columns all starting with the letter P, the 4’P Model for creative learning:
• Projects,
• Peers,
• Passion and
• Play.

Resnick developed a new version of LOGO called SCRATCH designed only for creative learning by offering a very different approach to coding. Coding is not any more a set of technical skills but a new way of thinking and personal expression.

Projects
„Scratch was designed with projects in mind.” [5] Students learn better through active working on topics meaningful for them. Learning is more efficient via projects and when using proper tools. This diversity of projects is a reflection of the diversity of interests of young people. Therefore instructions should be:
• cross-disciplinary • project-oriented • targeted • have a practical attitude • and first and foremost be creative.

Peers
„Encourage collaboration, sharing and help children to learn to build on the work of others. Coding shouldn’t be a solitary activity“. [7]

Learning thrives as a social activity, when people exchange their ideas, work on common targets and share their results. We believe that interaction with peers should be a central element in the learning process. So much learning can be exciting when it is team-oriented and appropriate to age and background. When teaching coding we must also focus our attention to choose the right level of abstraction.

Passion
Teaching should raise enthusiasm, reason the doing and engender creativity. When working on projects which are meaningful, challenging and kidding students work harder, longer and more efficient. That leads to success and sustainability of the learning process.

Play
Playing is the way of teaching that will support the creativity of our students. Learning to code should support experiments, lead to personal limits, urge the students to rise and always allow to try new ways..

VI. CONCLUSION

At the end we want to return to the starting point of the history of IT didactics and finally propose our conclusion and the idea which underlying this paper.

BASIC (an acronym for Beginner's All-purpose Symbolic Instruction Code) is a general-purpose programming languages whose design philosophy emphasizes ease of use. In 1964, Kemeny and Kurtz created the original BASIC language at Dartmouth College. They wanted to enable students in fields other than science and mathematics to use computers and to mediate them a feeling for algorithmic thinking, problem solving and the impact of algorithms on their professional and personal life. (see Wikipedia)

We see two reasons why we propose that we should again put a spotlight on coding and algorithmic thinking in tertiary education today:
• Algorithms have an underestimated power in many areas of science and society.
• Coding offers new ways of creative learning
Sometimes a step back can be a step forward.

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Infrared investigation on the thermal field of the human face during the EEG session

Kalin Dimitrov\textsuperscript{1}, Stanio Kolev\textsuperscript{2}, Iglika Andonova\textsuperscript{3}, Tsvetan Mitsev\textsuperscript{4}

Abstract – This paper presents a study on human skin surface warming during EEG. The case is with EEG with Emotiv® brain computer interface. For the experiment was used the connection between the optical radiation of the objects themselves and their temperature. The study was conducted under laboratory conditions during a session with a wireless 14 channel EEG system. The measurements were done simultaneously at many points by using an infrared camera. The conditions in the rooms and the condition of the patients were taken into account. The emissivity coefficients of the objects studied were also considered. In this work is presented only the thermography analysis.

Keywords – Infrared thermography, medical applications.

I. INTRODUCTION

Technology evolves every day and we face new perspectives in the field of health - diagnostic and therapeutic. What is observed in the last few years, is the significant application of infrared imaging, usually in the field of diagnostics. However, the potential of this technology in contemporary medicine is still to be explored in further detail. The current paper is an attempt to broaden the view and deepen the understanding of some of the existing diagnoses through the analysis of data provided by a thermal camera [1-13]. The primary analysis (EEG) is parallel with the infrared measuring [14-16].

II. CURRENT STATE OF THE PROBLEM

Much research that is done now focuses on the measurement of one standard diagnostic procedure at a time. The study of the correlations between the fundamentally different physical nature of the random processes is relatively rare [17-20]. The study of EEG together with optical methods mainly is done in the near infrared spectrum called Functional Near-Infrared Spectroscopy (700-900nm) [19,20]. The study in the far infrared range (8-13um), based on the objects’ own thermal radiation, is usually performed alone [2-4,13]. This is the reason to conduct this study.

III. EXPERIMENTS

The infrared pictures do not influence the main diagnostic procedure, so there are no special requirements on the part of doctors apart from the general requirements for hospital hygiene and rules. As the procedures that we use are non-invasive, they can be conducted outside the hospital [21,22]. The thermal camera used for data collection was FLIR E40, with thermal sensitivity of < 0.07°C and temperature range of (-20°C to 650°C) [23]. All examinations were performed in a sitting position in a quiet room at a constant room temperature of 20±0.5°C following an acclimatization period of 20 min keeping the hands free of any contact to the rest of the body or other objects [22]. For maximum accuracy, the camera was fixed on a stand and movement of the object was avoided. For the final analysis temperature values were determined and given in degrees Celsius (°C). Equally, the relative humidity showed stable values over time. All images were corrected using an emissivity factor of 0.98 for the human skin.

In this study, a series of images was made between certain intervals of time. The infrared pictures were taken at intervals of 20 sec. for 5 minutes. During the experiment were taken 4 groups of pictures. The first one from the first group is shown in Fig. 1.

Fig.1. One of the infrared images taken during the experiment with areas of interest

They were organized and conducted in four states - relaxation, intense thinking, relaxation and intense thinking. For intensive thinking we used successive arithmetic computations.
operations - removal of a number between 5 and 10 from 200. The aim was to make difficult but not impossible calculations.

Eight ellipses of interest were selected: E11, E12, E13 – on the forehead; E14, E16 – in the area of the cheeks; E15 – on the tip of the nose; E17 – on the chin; E18 – on the neck. We selected ellipses, not points, to eliminate probable human little movements and noises. For the areas where the human skin is observed, is selected a radiation coefficient 0.98 [21].

The processing was made with the original software of the camera - version FLIR Tools+ 5.3.1.

IV. ANALYSIS

Figure 2 shows all the data obtained after the processing of data in areas E11 to E18. On the ordinate are combined numbers of the measurements of the four groups. The first picture is marked with 1 and the last one - with 60.

![Fig.2. Results after averaging the data in the areas E11 to E12. On the x-axis is written the number of the measurement. It is a combination of four sets of measurements. The ordinate shows the temperature in degrees centigrade.](image)

The results in Fig.2 are difficult to comment on. For this reason we made calculations for a variance [24] for each dataset. For a more detailed analysis we split each set into two equal parts. The results are shown in Fig.3, Fig.4, Fig.5 and Table 1.

After a careful study of the results of Fig.3, Fig.4, Fig.5, we noticed that the overall variance for the first two measurements (Series1 and Series2) is significantly greater than the second two measurements (Series3 and Series4). There is an exception for the results from area E15. With the so selected times between the pictures, there is a clear correlation between variance and mental load for the following areas of interest: E12 - the first half of the data shows that the increase in mental load increases the variance; E4, E6 - in the first and in the second half of the data it can be seen that with the increase in mental load, variance decreases; E5 - in the first and in the second half of the data as well as the overall processing can be seen that when there is a reduction of mental load, variance is significantly increased.

After these calculations, we decided to do some of the 28 combinations of correlation [24] between the 8 areas of interest. The results are shown in table 2.

![Fig.3. Results after calculating the variance based on the first half of the data set for fields of interest. The x-axis denotes the number of the respective region E11 to E18. The four groups of measurements are denoted as Series1 to Series4. The ordinate represents the values of calculated variance.](image)

![Fig.4. Results after calculating the variance based on the second half of the data set for fields of interest. The x-axis denotes the number of the respective region E11 to E18. The four groups of measurements are denoted as Series1 to Series4. The ordinate represents the values of calculated variance.](image)
Fig. 5. Results after calculating the dispersion based on the whole data set for fields of interest. The x-axis denotes the number of the respective region El1 to El8. The four groups of measurements are denoted as Series1 to Series4. The ordinate represents the values of calculated variance.

<table>
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<td>0.03</td>
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The results of the correlation analysis showed significantly poor correlation in combination with El.5 than other areas. It is possible to think in the direction that the information we gain from this area is sufficiently different from the other areas of interest.

The analyzed data provides another perspective on the myriad applications of thermal images for medical purposes. Such an analysis can be very useful in providing a new understanding of widely used technology in terms of safety and effectiveness in diagnostics. Since IR imaging is noninvasive and does not bear any risks, it can be used wherever it is useful and feasible. There is also great potential for diagnostic medicine to look for links between different points of temperature and completely different phenomena.

V. CONCLUSION

The analyzed data provides another perspective on the myriad applications of thermal images for medical purposes. Such an analysis can be very useful in providing a new understanding of widely used technology in terms of safety and effectiveness in diagnostics. Since IR imaging is noninvasive and does not bear any risks, it can be used wherever it is useful and feasible. There is also great potential for diagnostic medicine to look for links between different points of temperature and completely different phenomena.

REFERENCES


Contemporary Approach to Teaching GSM with USRP and OpenBTS

Slavica Marinković¹, Amela Zeković², Ivan Pavlović³ and Milutin Nešić⁴

Abstract – The paper presents laboratory exercise implemented within third year Mobile Communications course in The School of Electrical and Computer Engineering of Applied Studies in Belgrade. The designed exercise follows the modern trend in teaching telecommunications based on software defined radio (SDR) platforms. The goal of the exercise is getting students relevant hands-on experience about organization and characteristics of Global System for Mobile Communication (GSM) system and motivating students to study wireless communication systems. GSM base station system is implemented with Universal Software Radio Peripheral (USRP) hardware and OpenBTS software. Students’ experience with the new laboratory exercise was evaluated by questionnaire.

Keywords – Mobile communications teaching, Laboratory exercises, GSM, USRP, OpenBTS.

I. INTRODUCTION

Software-defined radio is a system with characteristics that can be changed by software, that is, without the need to change system hardware components. In SDR the components that have typically been implemented in hardware in traditional radio systems are implemented in software, which allows for easy reconfigurability. Apart from being innovative wireless technology emerging in commercial market, SDR platforms offer great opportunities in enhancing practical teaching in the field of wireless and mobile communications [1]. The costs of SDR systems are minimal compared to conventional radio and network equipment and therefore enable academic institutions to deliver relevant, real world, practical exercises. The other important impact on the telecommunication engineering education of the current industry trends in SDR development and applications is that these changes inspire integrated SDR curriculum design [2]. The main advantages of SDR technology is flexibility in creating different communication technologies with little hardware components and usage of free, open source, publicly available software, which together makes this a very cost effective solution for various communications systems implementation. This allows more rapid communications system development and testing. Some of the examples of the implemented communications systems are: FM radio transmission and reception, digital video signal transmission, radio frequency identification, cognitive radio systems.

One of the very popular hardware platforms used for research and teaching in academia is universal software radio peripheral (USRP) [3,4]. This platform is commonly combined with LabView [4], or GNU radio software [5] to create software defined radio. Block diagram of the SDR platform is shown in Figure 1. Radio Frequency (RF) front end is used for signal transmission and reception. Intermediate frequency part of the USPR is used for analog to digital and digital to analog conversion (ADC/DAC) and signal processing by the Field Programmable Gate Array (FPGA) that can include filtering, modulation and demodulation as well as digital up conversion (DUC) or digital down conversion (DDC). The last block is used for baseband signal processing in software run at personal computer.

![Block diagram of the SDR platform](image1)

In our laboratory exercise the software run on PC is OpenBTS application [6], open source software for GSM base transceiver station (BTS) implementation. Open BTS together with USRP implements GSM access point which allows GSM compatible phones to communicate. Open BTS is the first free open source implementation of the standardized GSM protocol stack. This application implements air interface of the GSM standard (Um interface) and mobile stations (MS) see identical interface as in the case of conventional GSM systems. The rest of the network differs from the conventional GSM in that, that it uses Internet Telephony protocols [7]. The Session Initiation Protocol (SIP) and Real-time Transport Protocol (RTP) are the two protocols that OpenBTS uses to convert GSM traffic into voice over Internet Protocol (VoIP) traffic [7]. Open source software Asterisk Private Branch Exchange (PBX) [8] is used to connect calls. OpenBTS GSM system components are shown in Figure 2 [7].

![OpenBTS GSM system components](image2)

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GSM system architecture and Um interface are studied in detail theoretically in lectures. What was lacking was a practical experience with the GSM Um interface parameters that would help students to faster adopt knowledge in the field. The implemented exercise is based on reference [7].

Hardware that we used consists of USRP N210 with SBX daughterboard, GSM quad band antenna, PC and mobile phone. The installed software is Ubuntu 14.04LTS, OpenBTS 5.0, ASTERISK 11.7.0.4. The laboratory set up is shown in Fig 3.

II. OVERVIEW OF LABORATORY EXERCISE

Laboratory exercise is divided in four sections: GSM configuration, identification of GSM users, testing GSM services, and measuring signal quality.

A. GSM Configuration

Within “GSM Configuration” part of the laboratory exercise students gain experience with GSM system parameters, revise knowledge of frequency bands, downlink and uplink frequency separation, received signal strength indicator (RSSI) and examine relationship between noise levels and signal strength in respect to changes in transmit output power and receive and transmit antenna orientation.

Students set frequency band of GSM to 900MHz and select uplink/downlink channel pair by setting ARFCN (Absolute Radio Frequency Channel Number) to 124. This channel is not used by mobile operators in Serbia. The other parameters are set to default values.

Apart from examining the frequency settings, students get acquainted with the other characteristics of mobile communication systems by inspection of other parameters such parameters for setting maximum expected delay spread which is used for equalization, parameters for minimum and maximum output power used for output power control and parameters for target RSSI and signal to noise ratio (SNR) used for mobile station (MS) power control loop. Figure 4 shows an example of configuration parameters.

Students check the noise level and check whether uplink RSSI for MS is higher than noise level for at least 10 dB which was set by target SNR parameter.

It is further demonstrated that exists mutual influence of transmit and receive signal paths. This done by observing how noise levels change when transmit signal power is reduced and when antennas positions are changed.

B. Identification of GSM Users

Within “Identification of GSM Users” part of the laboratory exercise students get familiarized with numbers that are used for identification of mobile subscribers in GSM: IMSI (International Mobile Subscriber Identity), TMSI (Temporary Mobile Subscriber Identity), MSISDN (Mobile station ISDN Number), and IMEI (International Mobile Equipment Identity).

Concrete tasks comprise of checking the list of users that have requested interaction with openBTS. This list displays IMSI, TMSI and IMEI numbers as well as paramether AUTH that denotes whether the users have been authenticated. Figure 5 shows an example of displayed parameters for users connected to openBTS system.

Students check IMSI and IMEI numbers by mobile phone application on the phone and compare it to the one reported by openBTS.

In order to be able to authenticate users and register them with the openBTS GSM network, it is necessary to create entries in the database of subscriber information that replaces GSM Home Location Register (HLR) found in a conventional GSM. Students put the following entries in the database: user name, IMSI and MSISDN, and check whether the authentication has been successful.

C. Testing GSM Services

Within “Testing GSM Services” part of the laboratory exercise, students get to test voice and SMS service.

After users are registered with the network, the services can be checked by dialing test numbers predefined in the Asterisk PBX. Students send test message to 411 (predefined test number) and get, in a reply, IMSI and MSISDN numbers as parts of SMS, Figure 6 (on the next page).

By calling the test number 2602 students check the reception of the test tone. It is clearly heard in the case of good quality of communication channel. The loss of information can be heard as tone interruptions.
Students further perform echo call test in order to check both uplink and downlink connection. In an echo call test the voice message that has been sent by MS in the uplink channel is sent back to MS on the downlink channel.

**D. Measuring Signal Quality**

Within "Measuring Signal Quality" part of the laboratory exercise, students get familiarized with signal quality measures such as SNR and Bit Error Rate (BER) in GSM.

In this part of the exercise students make a two party call and examine what channels are used and what are their characteristics. They also examine the change of the characteristics of the links as the users are increasing distance from the base station.

Figure 7 shows the results for the call established between the two users when both users and base station are in the same room. The parameters that are identified are the following: the users use two channels (TN1 and TN2) which are full rate traffic channels on time slots 1 and 2 of the C0 ARFCN. Transmit power (TXPWR) for both users is 5dBm. RSSI for user with IMSI 22013003283793 is -23 dB and for user with IMSI 22013003283791 is -37 dB. BER is zero percent.
Figure 8 shows the results when the user with IMSI number 22013003283793 is in another room. It can be seen from Figure 8 that by increasing distance of the MS from the base station, the MS transmission power is increasing from 5 to 13 dBm, in order to maintain target RSSI at -50dB. At the same time SNR has decreased and the BER is increased to 1.03 percent.

Figure 9 shows the results when the user with IMSI 22013003283793 is one floor below base station. Further degradation of SNR and BER can be observed.

III RESULTS OF STUDENT SURVEY

One of the main reasons for introducing this laboratory exercise was to motivate students to learn about complex technologies used in contemporary mobile communications. In order to examine students’ overall experience with the newly introduced laboratory exercise, a questionnaire has been created. The questionnaire has been filled in by 33 students. The questionnaire consists of ten questions grouped in three categories.

The first category of questions asks students to evaluate their knowledge of SDR and GSM before and after the laboratory class. Majority of students have answered that their understanding of GSM and SDR systems has improved after attending the laboratory class.

The second group of questions refers to evaluating complexity of the examined system and the complexity of the laboratory exercise. Majority of students have evaluated complexity of laboratory exercise as moderate.

The third group of questions evaluates student opinion on how the exercise contributes to understanding of SDR and GSM concepts, and whether it inspires further interest in studying wireless/mobile communication systems.

IV CONCLUSION

Laboratory exercise “GSM mobile technology with SDR and openBTS” significantly improves teaching of GSM by integrating the teaching of theory with the practical experience. Students get exposed to modern teaching tools used at world’s top universities. Student survey results show that the introduced laboratory class is well accepted. We plan to further advance the study of GSM in the future by using protocol analyzer software Wireshark and to introduce laboratory on UMTS.

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