An Overview and Tutorials on Modeling and Simulation

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Abstract— The modeling and simulation are the most important challenges to the researcher to present the system reality and study the different metrics of it. This article provides the short overview to assist the new researchers toward their goals. With aid of differ scenarios related to an engineering domain the designers have an ability to answer critical questions about modeling and simulation.

Index Terms— Model, Simulation

I. INTRODUCTION

Initially before entering the modeling and simulation we present the scientific research to assist the researcher to great there goals. The main question "What is scientific research?" is a vital question to be taught and grasped to students and novice researchers at colleges. While scientific research is objective by definition, it seems it initiated by subjective incidents like intuition and instinct, this paradox confuse the researchers. To address this problem, we proposed design of simple high abstracted illustrated drawing to communicate a massage answering "what scientific research is", we anticipated that researchers will understand the meaning of Scientific Research significantly and more precisely than if they would take a normal textual introduction about it.

The illustration illustrate in Figure-1 a butterfly flying in incomplete path forming the "research Problem", in Figure-2 the researcher has an intuition as "hypothesis" that the butterfly is flying in a zigzag line, this intuition should be tested and completed with: (1) direct experiments. (2) Consistent logic. (3) Citation from other proved researches. And those three components can be used on any places to fill the gaps to complete the intuition.
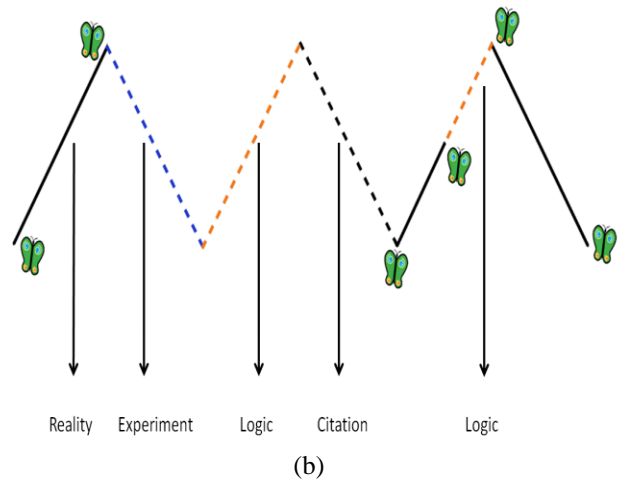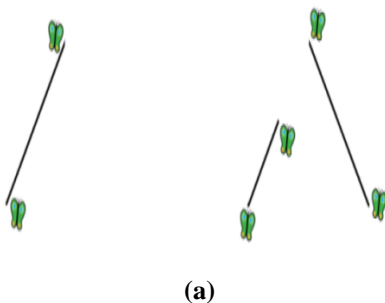

(a)

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(b)

Figure 1 Butterfly flying models (a) Complete path   (b) Zigzag line

The modeling (i.e., System) according to *Webster's International Dictionary*, "A system (i.e., model) is an aggregation or assemblage of objects united by some form of regular interaction or interdependence; a group of diverse units so combined by nature or art as to form an integral; whole and to function, operate, or move in unison and often in obedience to some form of control….". Every system consists of components i.e. subsystem at lower levels and in the higher levels is a super-systems. The term "simulation" is normally used to describe the process of executing such a program with input parameters and to simulate the system under prescribed conditions [1], [2].

The Modeling and simulation is a field that is utilized in engineering, science, health science, business, education, and many other disciplines. Content comprises, but is not limited to geospatial technologies (i.e. GPS, GIS, remote sensing), gaming, medical and scientific imaging, animation, engineering drawing, transportation, distribution, warehousing, and architectural drawing.

The reset of this paper is structured as follow: Section-2 describes details of how to make precise modeling and the selection criteria's of suitable tools (taxonomy). The different scenarios are presented in section-3. The conclusion of this study is presented in sectio-4.

II. TAXONOMY OF MODELING AND SIMULATION

In this section, we discuss the taxonomy of Modeling and Simulation [3], [4] and [5] as depicted in Figure 2.
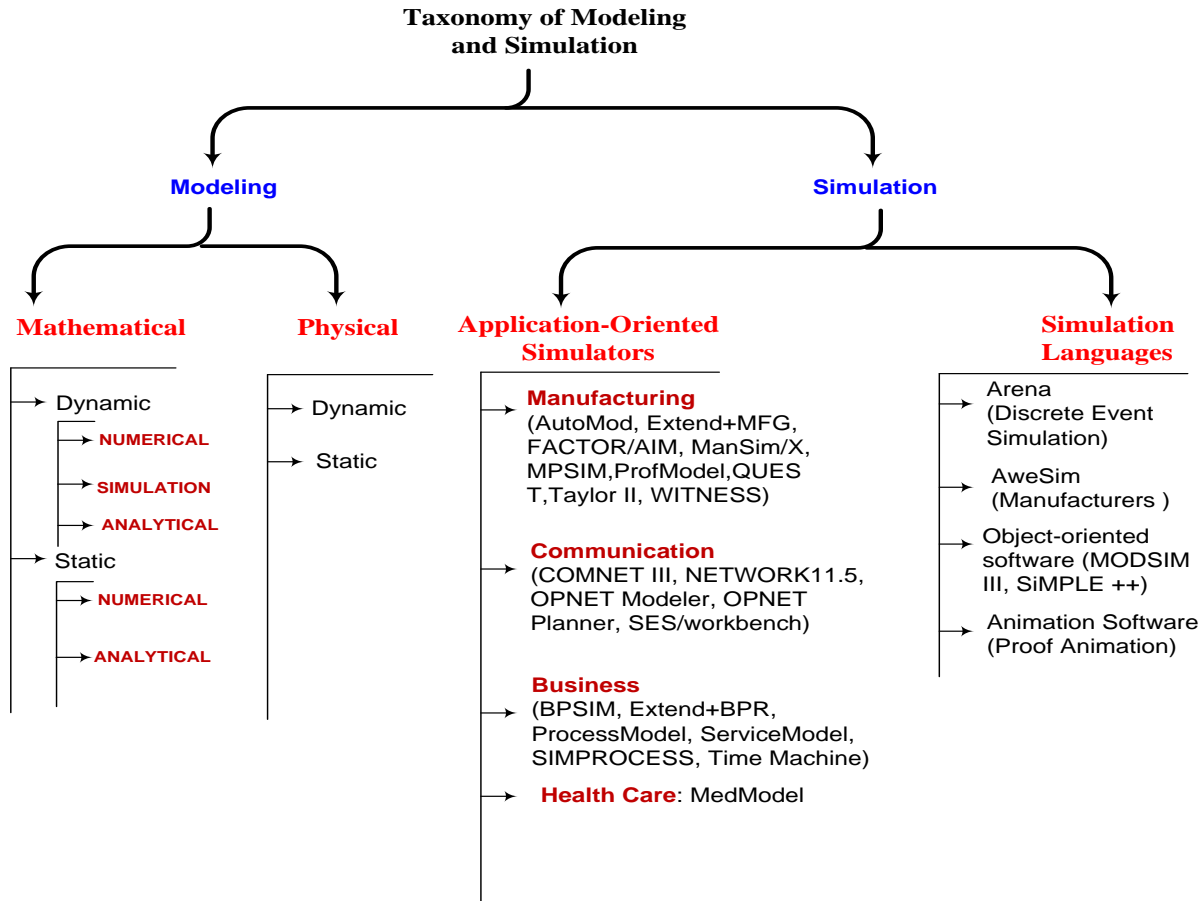
Figure 2: Taxonomy of Modeling and Simulation

Ultimately, Simulation can be divided into two categories: Simulation Languages and Application-Oriented Simulators. The Simulation Languages that belongs to this family are Arena, AweSIm, Object-Oriented Software (MODSM III, SiMPLE++) and Animation Software (Proof Animation). The application-oriented simulators include the manufacturing, communication, business and health care. The modeling has two branches: physical and mathematical. Both of them divided into numerical and Simulation. Details regarding associated with modeling are provided next.

A. Model

Ultimately, the models can be separated into two categories: physical and mathematical models. The physical model builds with tangible materials such as scale models, prototype plants to test the structure of it under certain conditions. It's a smaller or larger physical copy of an object. The physical model shows *where* and *how* system components will be deployed. It is a precise drawing of the physical arrangement of the system.

In Mathematical models used the mathematical Expression (Analytical queuing models, distribution probability, drawing, etc). Other kinds of classification of mathematical models are dynamic (i.e. change with time) and static (i.e. change constant with time). The models can be classified according to complexity, as shown in Figure **3** starting from white (*physical*) to black (*Esoteric*) through the conceptual model.

The Physical system is a collection of components, in which each component has its private manners, used for some purpose. Physical model can be defined as systems whose variables can be measured with physical devices that are quantitative such as electrical systems, mechanical systems, computer systems, hydraulic systems, thermal systems, or a combination of these systems.

The Conceptual model referrer to all the measurements are imaginary i.e. conceptual (These are complex systems) and in qualitative form as in psychological systems, social systems, health care systems, and economic systems. Abstract model are those systems in which the quantity of interest cannot be measured directly with physical devices.

The Esoteric models are the systems in which the measurements are not possible with physical measuring devices. These kinds of model are highest order of complexity model (Black color).
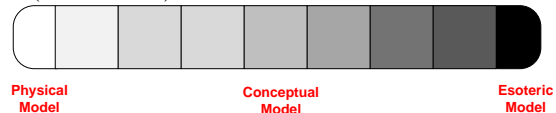

Figure 3 Classification models according to complexity

B. Simulation

It is the process of designing a model of a real or imagined system and conducting experiments with that model in duration time [6], [7].

Based on the behavior in which the state variables changes the simulations are usually referred to as either ***discrete event or continuous***. Discrete event refers to the fact that state variables change instantaneously at distinct points in time. In a continuous simulation, variables change

continuously, usually through a function in which time is a variable. In practice, most simulations use both discrete and continuous state variables, but one of these is predominant and drives the classification of the entire simulation.

In generally, the steps of modeling and simulation [8] depicted in Figure 4 as follow:

1. Define and formulate the issues
2. Start early to collect the necessary input data.
3. Put together a complete mix of skills on the team and involve the end-user.
4. Develop the model
5. Prefer the appropriate simulation tools
6. Perform simulation runs.
7. Compare the proposed model's metrics result under known conditions with the real or previous system.
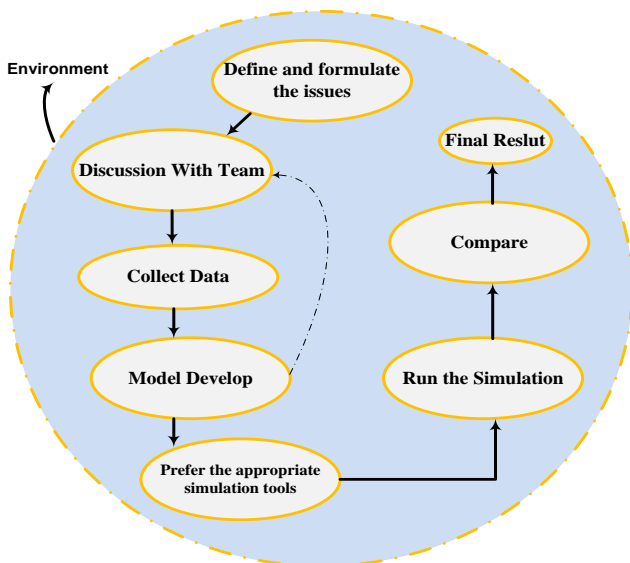

Figure 4: illustration of modeling and simulation

III. VARIOUS TUTORIALS SYSTEM:

This section provides different examples model system such as electrical, communication, SCADA and mechanical.

A. Electrical model

This section presents the basic example of the electric and electronic model. The essential structure block of electrical model contains resistor, inductor, and capacitor. The components are connected series with input voltage *(V)* and current *(i)*. The state model for the electrical system shown in following [9]:

$$i(t) = i_L(t) = i_C(t) = i_R(t)$$

$$V_L(t) = V - V_R - V_C \qquad (1)$$

$$\frac{di_L}{dt} = \frac{1}{L}\left(V - R*i(t) - V_C\right) \qquad (2)$$

$$\frac{dV_C}{dt} = \frac{i_C(t)}{C} = \frac{i(t)}{C} \qquad (3)$$

Number of state equations = number of dynamic elements = 2

Here, we may choose $\begin{bmatrix} i_L(t) & V_C(t) \end{bmatrix}$ as the state variables. Therefore, the state and output equations respectively can be written as:

$$\frac{d}{dt}\begin{bmatrix} i_L(t) \\ V_C(t) \end{bmatrix} = \begin{bmatrix} -R/L & -1/L \\ 1/C & 0 \end{bmatrix}\begin{bmatrix} i_L(t) \\ V_C(t) \end{bmatrix} + \begin{bmatrix} 1/L \\ 0 \end{bmatrix}e(t)$$

$$e_C(t) = \begin{bmatrix} 0 & 1 \end{bmatrix}\begin{bmatrix} i_L(t) \\ V_C(t) \end{bmatrix}$$

(4)

The simulation results of above mentioned MATLAB program are shown in Figure **5**. There is no unique way of selecting the state variable, i.e., we can select another set of state variables and therefore we will have different state and output equations. This can be illustrated by choosing $X_1 = i(t)$ and $X_2 = \dfrac{di}{dt}$ as the state variables in the previous example.
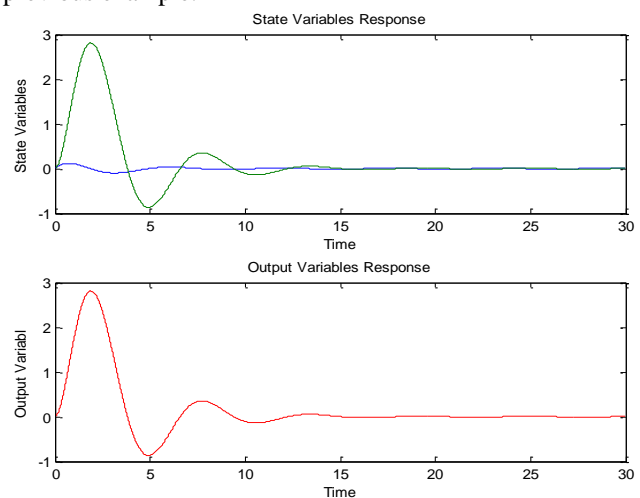

Figure 5 Steady State Results

B. Communication model

In communication, the data packets directly transmit between any two end users [10]. This model provides the BER performance of BPSK. With Binary Phase Shift Keying (BPSK), the binary digits '1' and '0' maybe represented by the analog levels $\pm\sqrt{E_b}$. The system model is as shown in the Figure 6.
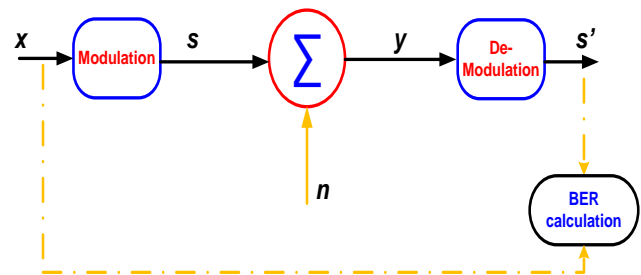

Figure 6 Communication system model

The channel models, computing the error probability and simulation analysis are presented in the following:

a. Channel Model

The transmitted waveform gets corrupted by noise n, typically referred to as Additive White Gaussian Noise (AWGN). The values of the noise n follow the Gaussian probability distribution function as in the following function:

$$p(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{-(x-\mu)^2}{2\sigma^2}}$$

(5)

with $\mu = 0$ and $\sigma^2 = \frac{N_0}{2}$.

b. Computing the probability of error

Using the derivation provided in [11] to obtain the error probability. The received signal, $y = s_1 + n$ when transmitted bit $'1'$ and $y = s_0 + n$ when transmitted bit $'0'$.

The conditional Probability Distribution Function (PDF) of y for the two cases whether transmits $'1'$ or $'0'$ are:

$$p(y|s_0) = \frac{1}{\sqrt{\pi N_0}} e^{\frac{-\left(y+\sqrt{E_b}\right)^2}{N_0}}$$

(6)

$$p(y|s_1) = \frac{1}{\sqrt{\pi N_0}} e^{\frac{-\left(1-\sqrt{E_b}\right)^2}{N_0}}$$

(7)

Assuming that $'s_1'$ and $'s_0'$ are equally probable i.e. $p(s_1) = p(s_0) = \frac{1}{2}$, the threshold $'0'$ forms the optimal decision boundary.

- If the received signal is $'y'$ is greater than $'0'$, then the receiver assumes $'s_1'$ was transmitted (i.e. $y > 0 \Rightarrow s_1$).

- If the received signal is $'y'$ is less than or equal to $'0'$, then the receiver assumes $'s_0'$ was transmitted (i.e. $y \leq 0 \Rightarrow s_0$).

With this threshold, the probability of error given s_0 and s_1 is transmitted is $p(e|s_0)$ and $p(e|s_1)$ respectively. Therefore, the total bit error probability to transmit $'1'$ or $'0'$ is given as:

$$P_b = p(s_1)p(e|s_1) + p(s_0)p(e|s_0)$$

(8)

Given that, if assumed that s_1 and s_0 are equally probable i.e. $p(s_1) = p(s_0) = \frac{1}{2}$, the bit error probability is,

$$P_b = \frac{1}{2} erfc\left(\sqrt{\frac{E_b}{N_0}}\right)$$

(9)

where the $erfc(x)$ is the Complementary Error Function and it is given as $erfc(x) = \frac{2}{\sqrt{\pi}} \int_x^\infty e^{-x^2} dx$

c. Simulation model

Utilize the Matlab source code for computing the bit error rate with BPSK modulation from theory and simulation. The following six steps provide the algorithm to evaluate the transmitting data:

1. *Generation of random BPSK modulated symbols '$+1$' or '-1'*

2. *Passing them through AWGN channel*

3. *Demodulation of the received symbol based on the location in the constellation*

4. *Counting the number of errors*

5. *Repeating the same for multiple SNR = Eb/No values.*

6. *Plotting the SNR against the BER*

The result shows that the theoretical BER, and the simulation results are identical.
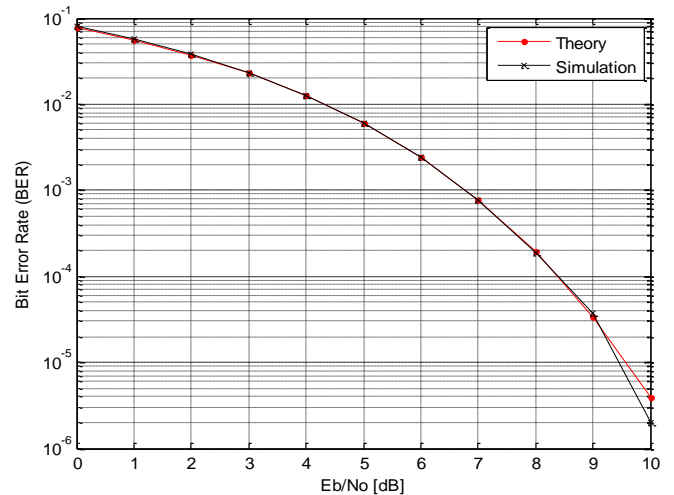

Figure 7 BER performance of BPSK

C. SCADA model

SCADA is an industrial control system at the core of many modern industries such as manufacturing, energy, water, power, transportation and many more [12]. SCADA systems deploy multiple technologies that allow organizations to monitor, gather, and process data as well as send commands to those points that are transmitting data. This section shall

help engineers to remotely control the industrial processes such as motor and pumps.

The primary goal of this model to design and implement a system which can be able to monitor and control processes environment using Labview with Arduino. The implementation was successful. The system will replace the manual control and monitor. This system will save time and money. There is no need to monitor or operate the system manually.

In this system all sensors and switches are predefined in LABVIEW's block [13] diagram parts to simulate the industrial environment. The front panel will be user interface, from the user interface: 1) the user can automatically switch ON or OFF devices, units or equipment. 2) The user can know if the device is ON or OFF. 3) The user can know the current value of each sensor. LABVIEW will send control signal to ARDUINO to control device and ARDUINO collect sensor's values and send it to LABVIEW to display it.

IV. System Model

The Components Description of model are in the follows:

a. Arduino Uno:

Arduino is a microcontroller board based on ATmega328. It has 14 digital input/output pins (of which 6 of them can be used as PWM output) 6 analog inputs, a 16 MHz crystal oscillator, USB connection, a power jack, an ICSP header and reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC to DC adapter or battery to get started.

b. Max232 Driver

The MAX232 is a dual driver/receiver that includes a capacitive voltage generator to supply TIA/EIA-232-F voltage levels from a single $5\text{-}V$ supply. Each receiver converts TIA/EIA-232-F inputs to $5\text{-}V$ TTL/CMOS levels. These receivers have a typical threshold of $1.3\text{-}V$, a typical hysteresis of $0.5\text{-}V$, and can accept $\pm 30\text{-}V$ inputs. Each driver converts TTL/CMOS input levels into TIA/EIA-232-F levels.

c. LM35 Temperature Sensor:

The LM35 is an integrated circuit sensor that can be used to measure temperature with an electrical output proportional to the temperature.

d. DC Motor

e. Light Emitted Diode (LED)

f. Serial Communication

V. Circuit Diagram

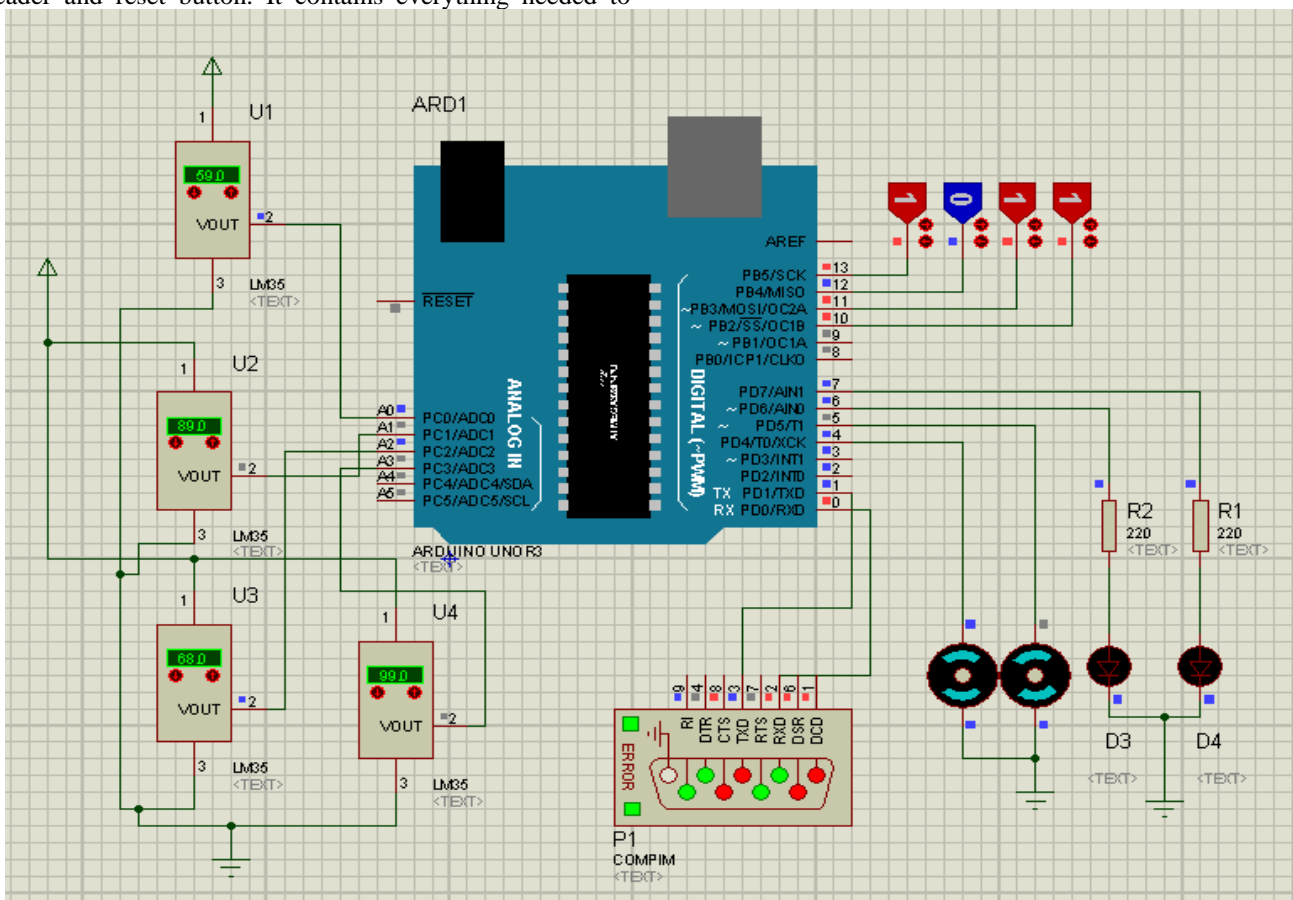The circuit diagram of the proposed system shown in Figure 8.

Figure 8: Circuit Diagram of the proposed system

VI. Software Program

The software programming of the Arduino is done in 'C' language. We have used Labview program to build the human machine interface or graphical user interface. Labview is a graphical programming language, the block diagrams of

the project shown in Figure **9** and Figure **10**. In Labview programming side, all time slots are defined and some formulae are used for different conversion and comparisons , all those blocks are placed inside a while loop as the system runs continuously.
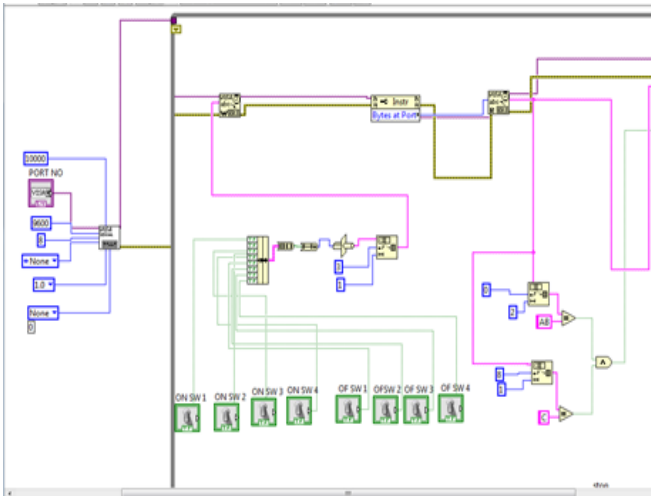
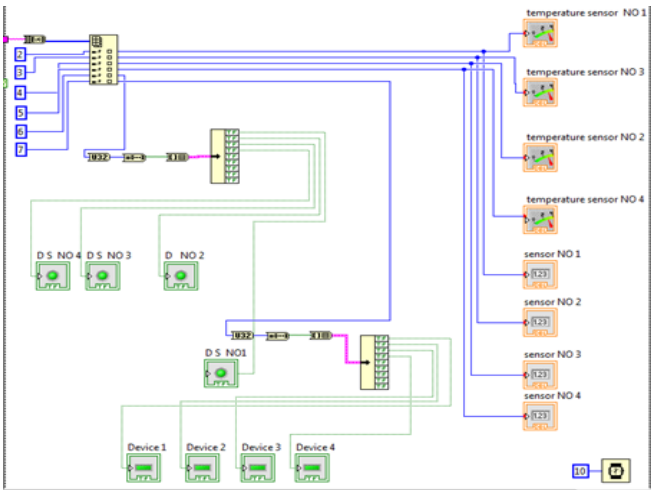
Figure 9: Labview Programming Code 1

Figure 10: Labview Programming Code 2

In GUI much operation can do the following: The user can automatically switch ON or OFF devices, units or equipment. The user can know if the device is ON or OFF. The user can know the current value of each sensor.
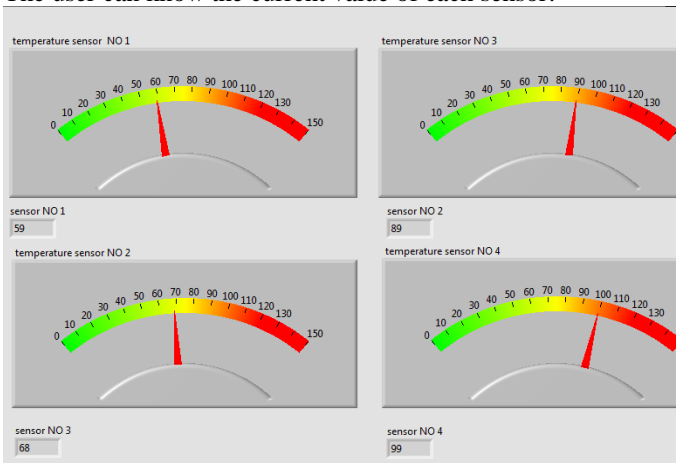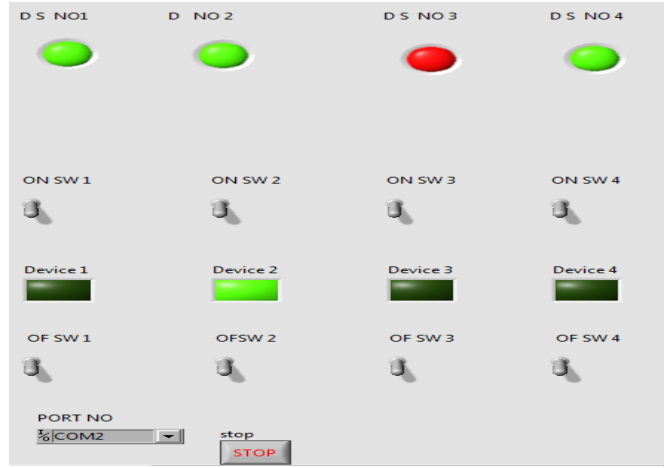

Figure 5: GUI for Analog Sensors

Figure 6: GUI for Digital Sensors and Control Devices

VII. RESULT AND DISCUSSION

We have two parts in this model, supervise and control.

a. **SUPERVISE**:

In this part the Arduino analog and digital sensors and transfers these readings to the Labview through serial communication, to display analog and digital sensors values in indictors.

b. CONTROL:

In this part we control LEDs, MOTOR and FAN from LABVIEW user interface that contains switches to control it. So when we press one of these switches (motor switch for example), the Arduino will order the motor to operate, after that the Arduino refer signal to the Labview that the motor is operate, then LABVIEW display these signal by indicator that the motor is operate, these steps happen also to the LEDs and the FAN, and all that according to the program.

We recommend that if the system wanted to implement in virtual use, to make better interface circuit between the microcontroller (Arduino) and devices or equipment that need to control it and between Arduino and computer.

VIII. MECHANICAL MODEL

The basic of the mechanical models are presented in [1] start from page (46) to page (77). This model describes the transient pressure in a pipe. Firstly, the Euler equation is derived by the application of Newton's second law to a small cylindrical control volume (C.V) of fluid at the pipe produce the Euler equation. The principle is to equate the forces acting on the C.V (pressure force, weight and shear force) with mass multiplied by the fluid acceleration as shown in Figure 11. The resultant equation is known as Euler equation [14], equ (10).
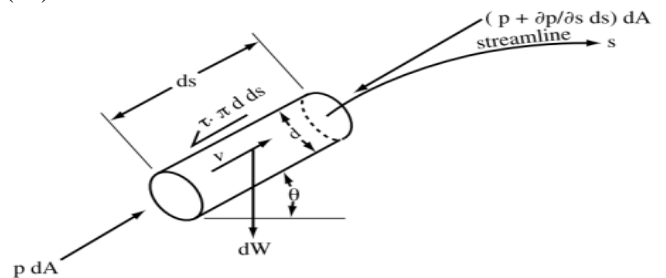

Figure 11: Forces on a cylindrical fluid element

$$\frac{1}{g}\frac{dV}{dt} + \frac{1}{\gamma}\frac{\partial p}{\partial S} + \frac{dz}{dS} + \frac{f}{D}\frac{V|V|}{2g} = 0 \qquad (10)$$

1. Conservation of Mass

The application of the conservation of mass and combined with the elastic pipe theory on the control volume shown in Figure 12 produced the conservation of mass equation [14], equ.11.
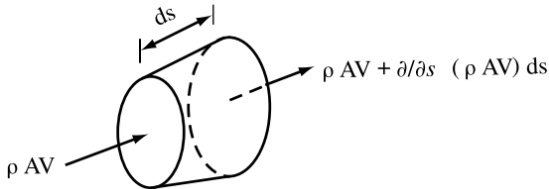

Figure 12: Control volume coinciding with the interior surface of the pipe

The conservation of mass and the motion in elastic pipe can be given by

$$a^2 \frac{\partial V}{\partial s} + \frac{1}{\rho}\frac{dp}{dt} = 0 \qquad (11)$$

When we combine equ.1 &2 the fluid in the pipe can be totally modeled because they covered the forces and the mass balance in C.V. The above two equations can be used to describe the transient pressure wave in a pipe when the flow was suddenly objected, for example by valve (sudden closure). In equ.10&11 when:

$$\tau_0 = \frac{1}{8} f\rho V|V| \qquad (12)$$

The pressure $p(s,t)$ can be expressed in the form of the piezometric head H via the relation $p = \rho g(H - z)$ and the full derivative of (d/dt) represent the temporal and convective partial derivative terms. For example

$$\frac{dV}{dt} = \frac{\partial V}{\partial t} + V\frac{\partial V}{\partial s} \qquad (13)$$

By applying this in Equ.(10) and Equ.(11) and similarly for (dH/dt) .By the neglects of the density variation and the nonlinear terms with some algebra and partial derivative give

$$a^2 \frac{\partial^2 H}{\partial t^2} = a^2 \frac{\partial^2 H}{\partial s^2} \qquad (14)$$

Equation (14) known as wave equation, also can be in V(s, t) variable by the same manner. The solution of equation (14) for either H. or V. gives the behavior of the wave. The solution conducted by using two independent variable u(t, s), v(t, s). The application of the chain rule of differentiation gives

$$4a^2 \frac{\partial^2 H}{\partial u \partial v} = 0 \qquad (15)$$

Since $a2 > 0$

But, from a Chain rule, it follows that H must be expressible as a sum of a function of u and a function of v, such as

$$H(s,t) = F_1(t + s/a) + F_2(t - s/a) \qquad (16)$$

Functions F_1 and F_2 are each wave forms; either or both may exist in a particular problem, depending on the particular initial and boundary conditions. The solution is wave traveling at constant speed a, in both directions along the s-axis. The conclusion is F1 describes a left-moving wave; F2 describes a right moving wave form. The general solution to Eq. (15) is then a superposition of any number, one or many, of left- and/or right-moving waves.

2. Mathematical Model

From the basic equ.10&11 with $p = \rho g(H - z)$ principle and separation of (dV/dt) and (dH/dt) into their component parts and by applying the characteristic method linearization principles, then the result become:

$$\frac{dV}{dt} + \frac{g}{a}\frac{dH}{dt} - \frac{g}{a}V\frac{dz}{ds} + \frac{f}{2D}V|V| = 0 \qquad (17)$$

When: $\qquad \dfrac{ds}{dt} = V \pm a$

The proposed model (equ.17) was described by exact method of characteristic with linear interpolation (EMOC) [15]:

$$V_{Pi(N+1)}^{J+1} = \frac{1}{2}\left(\beta_{i(N-1)in}^{J} - \beta_{i(N+1)out}^{J} + C_i\Delta t \sin\theta\left(V_{Li(N-1)}^{J} - V_{Ri(N+1)}^{J}\right)\right)$$

$$H_{Pi(N+1)}^{J+1} = \frac{1}{2}\left(\left(\beta_{i(N-1)in}^{(18)} + \beta_{i(N+1)out}^{J}\right)(1/C_i) + \Delta t \sin\theta\left(V_{Li(N-1)}^{J} + V_{Ri(N+1)}^{J}\right)\right)$$

$$\beta_i = \begin{cases} C_iH_{Li} + V_{Li}^{(19)} - AK_iV_{Li}|V_{Li}| & \text{for pipe in} \\ C_iH_{Ri} - V_{Ri} + AK_iV_{Ri}|V_{Ri}| & \text{for pipe out} \end{cases} \qquad (20)$$

$$Ak_i = \frac{f_i\Delta t}{2D_i} \qquad \text{and} \qquad C_i = g/a_i$$

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left(\frac{5.02\log_{10}\left(\text{Re}/\left(4.518\log_{10}\left(\text{Re}/7\right)\right)\right)}{\text{Re}\left(1 + \left(\text{Re}\right)^{0.52}/\left(29\left(D/k\right)^{0.7}\right)\right)} + \frac{1}{3.7\left(D/k\right)}\right)$$

(21)

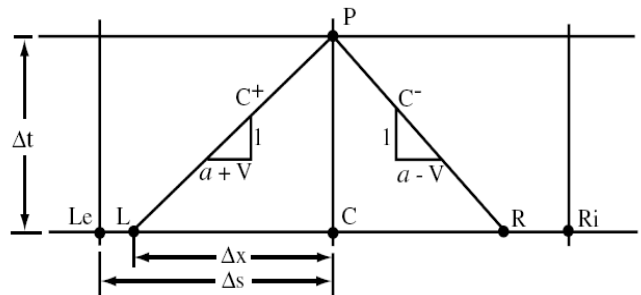Equ.18&19 applicable only when $\Delta x \le \Delta s$ in Figure 13

Figure 13: Parameters in the interpolation procedure

The proposed model was examined for rapid valve closure in downstream of a conduit at the valve's node, and in node bifurcation of pipe network as follow:

The proposed model used to test two single pipe systems; system1 reservoir at upstream and valve at downstream, system2 pump at upstream and valve at downstream. In sudden closure the maximum pressure in system1 occurs at the valve node but in system2 at the pump node, as shown in Figure 14.
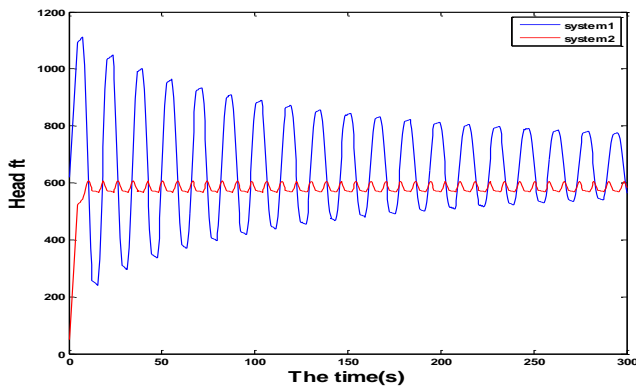
Figure 14: Comparison of pressure head at downstream for system1 and system2

IX. CONCLUSION AND RECOMMENDATION:

Modeling and simulation are significant tools of systems engineering that have now become a middle action in all disciplines of engineering and science. Furthermore, it's important for the design of novel systems as they enable us to predict the system behavior before the system is actually built. Modeling and simulation also allow us to analyze systems accurately under varying operating conditions.

The aim of this paper is to provide a comprehensive coverage of important aspects of modeling and simulation of physical as well as conceptual systems. Other kinds of model example related to engineering are Fuzzy Systems, Artificial Neural Network and Genetic Algorithms.

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