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Design and Implementation of PID Controller for Insulin Pump Using FPGA

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Abstract: Diabetes is a chronic metabolic disorder affecting 422 millions of people worldwide .The pancreas of those people either unable to produce insulin or do not produce enough insulin. When this occurs, blood glucose stays in the blood and cells cannot absorb as well as can not convert the sugars into energy. This disorder will lead to death especially people living in low- and middle-income countries; 1.6 million deaths are directly attributed to diabetes each year. In order to reduce number of death and help patients the insulin pump is used (a medical device used for the administration of insulin in the treatment of diabetes mellitus). This project presents the design and the implementation of Proportional –Integral-Derivative PID controller by using Field Program Gate Array FPGA for the insulin pump system.

The controller gains Kp , Ki and Kd was founded by using trial and error method .These gains are responsible for generating the required insulin that keep the glucose within acceptable level .

Twenty bit was used to represent the data of system as a singed two's complement fixed point number. the Device (3s500efg320-4) is selected to hard ware implementation and the proposed design summary as follows : Number of Slices (305 out of 4656 6%), Number of Slice Flip Flops (62 out of 9312 0%), Number of 4 input LUTs (217 out of 9312 2%) ,Number of IOs (102) and Number of bonded IOBs (0 out of 232 0%).

The FPGA hardware implementation results was verified with the MATLAB simulation result and they were approximately identical.

Introduction

1.1. General considrations

Insulin is a hormone that is responsible for allowing glucose in the blood to enter cells, providing them with the energy to function. A lack of effective insulin play a key role in the development of diabetes.Three main groups of insulin are available:

1. Fast-acting insulin: this type include, Rapid-acting insulin a)

b) Regular-acting insulin

2. Intermediate-acting insulin

3. Long-acting insulin

In some people, the immune system attacks the islets (cells in the pancreas called islets produce the hormone), and they cease to produce insulin or do not produce enough .When this occurs, blood glucose stays in the blood and cells cannot absorb them to convert the sugars into energy .This is the onset of type 1 diabetes, and a person with this version of diabetes will need regular shots of insulin to survive.

Type 2 diabetes will develop when the islets cannot produce enough insulin to overcome insulin resistance.

An insulin pump is a medical device used for the administration of insulin in the treatment of diabetes mellitus, also known as continuous subcutaneous insulin therapy ,The pump is about the size of a smartphone .

Insulin pumps use short-acting and rapid-acting insulin, but not long-acting, since the pump is programmed to deliver a small amount continuously to keep your blood sugar levels even.

1.2. The aim of the project

Design the PID controller for the insulin pump which calculates the insulin deliver to the human body for people who suffer from diabetes using Field Programmable Gate Array (FPGA), These systems monitor blood sugar levels and deliver an appropriate dose of insulin when required.

1.3. The project layout

This Project consists of four chapters:

Chapter One:

This chapter includes a general consideration and explain the aim of this work.

Chapter Two:

Presents the biomedical aspect for the project .

Chapter three:

Explain the digital design steps by using fpga

Chapter four:

Present conclusions and suggestion for the future work.

Chapter Two

Theoretical Background

2.1. The introduction

This chapter will provide information about the pancreas(anatomy ,blood vessel ,function), the glucose and its regulation , insulin , insulin pump ,PID controller , transfer function , FPGA .

2.2. Anatomy of the pancreas:

The pancreas is an elongated, tapered organ located across the back of the belly, behind the stomach. The right side of the organ—called the head—is the widest part of the organ and lies in the curve of the duodenum, the first division of the small intestine. The tapered left side extends slightly upward—called the body of the pancreas—and ends near the spleen—called the tail.

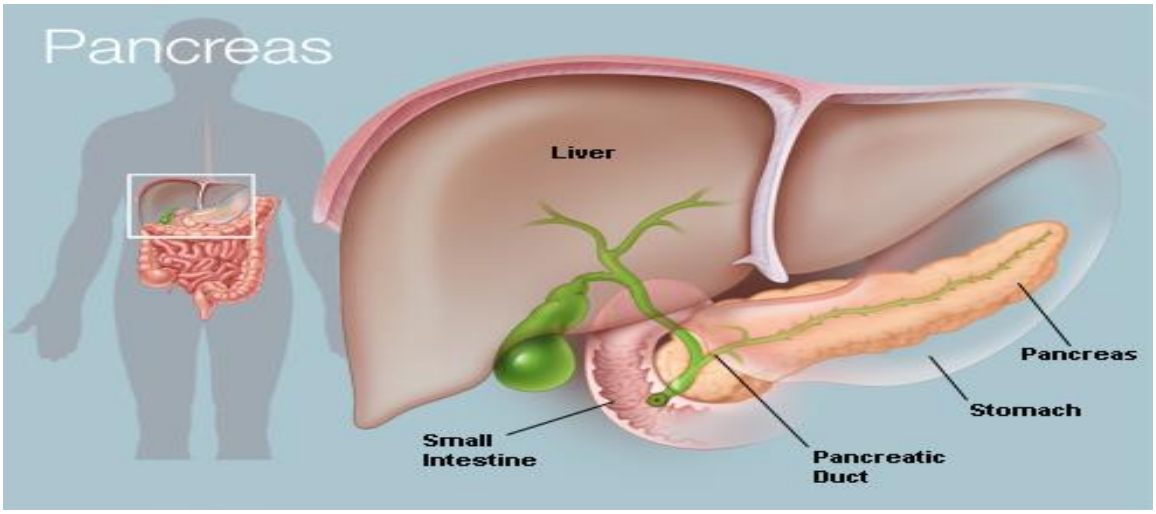


Figure (2-1) : Anatomy of the pancreas

The pancreas is made up of 2 types of glands:

- **Exocrine.** The exocrine gland secretes digestive enzymes. These enzymes are secreted into a network of ducts that join the main pancreatic duct. This runs the length of the pancreas.
- **Endocrine.** The endocrine gland, which consists of the islets of Langerhans, secretes hormones into the bloodstream.[1]

Blood vessels of pancreas: 2.2.1.

The pancreas receives its blood supply from several sources. The uncinate process and head are supplied by the superior and inferior pancreaticoduodenal arteries, which are branches of the gastroduodenal and superior mesenteric arteries respectively. Each pancreaticoduodenal artery has anterior and posterior branches that project along the respective faces of the pancreatic neck where they form pancreaticoduodenal arcades and supply them with arterial blood.

In turn, the body and tail of the pancreas are supplied by pancreatic arteries that stem from the splenic, gastroduodenal, and superior mesenteric arteries. The major contributor is the splenic artery.[2]

2.2.2. Functions of the pancreas:

The pancreas has digestive and hormonal functions:

- The enzymes secreted by the exocrine gland in the pancreas help break down carbohydrates, fats, proteins, and acids in the duodenum. These enzymes travel down the pancreatic duct into the bile duct in an inactive form. When they enter the duodenum, they are activated. The exocrine tissue also secretes a bicarbonate to neutralize stomach acid in the duodenum. This is the first section of the small intestine.
- The main hormones secreted by the endocrine gland in the pancreas are insulin and glucagon, which regulate the level of glucose in the blood (100 -125 mg\dl fasting blood sugar level ,80-140 mg\dl random blood sugar level), and somatostatin, which prevents the release of insulin and glucagon.[1]

2.2.3. Regulation of glucose metabolism:

The liver has a major role in the control of glucose homeostasis by controlling various pathways of glucose metabolism, including glycogenesis, glycogenolysis, glycolysis and gluconeogenesis.

- Glycogenesis: is the process of glycogen synthesis, in which glucose molecules are added to chains of glycogen for storage. This process is activated during rest periods following the Cori cycle, in the liver, and also activated by insulin in response to high glucose levels.
- Glycogenolysis is the breakdown of glycogen (n) to glucose-1-phosphate and glycogen (n-1). Glycogen branches are catabolized by the sequential removal of glucose monomers via phosphorolysis, by the enzyme glycogen phosphorylase.

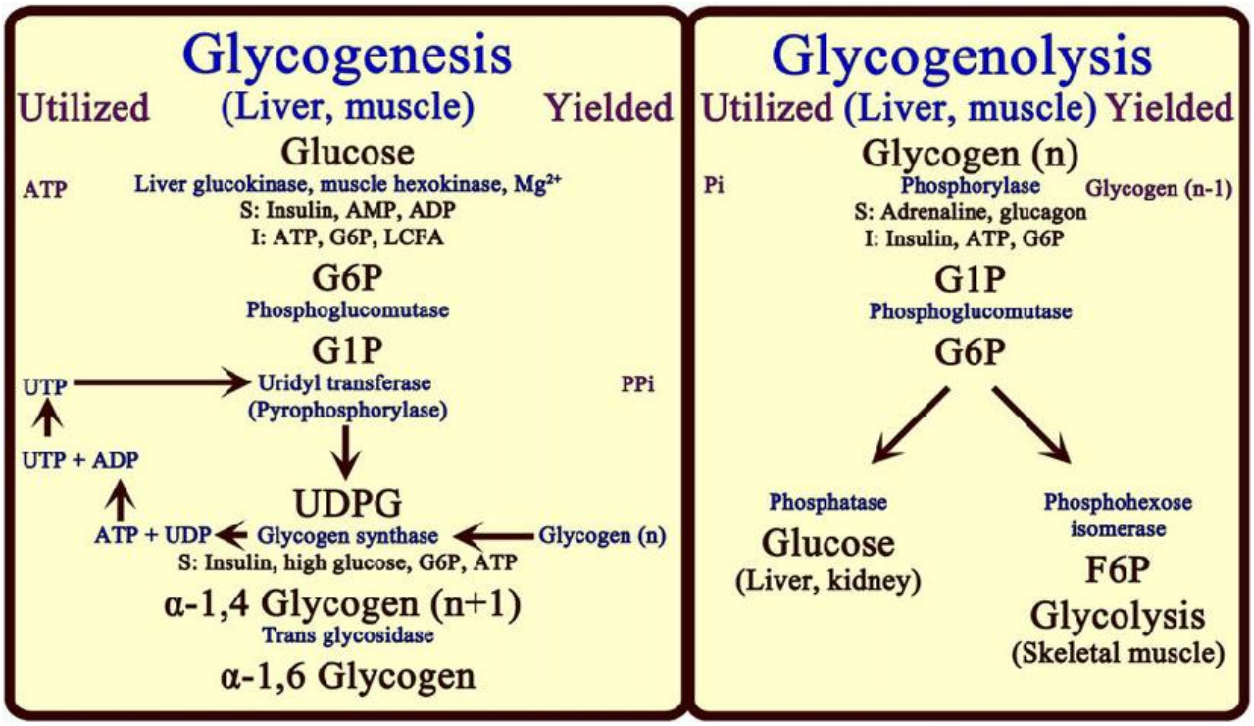


Figure (2-2): Glycogenesis & Glycogenolysis method

Glycolysis is the metabolic pathway that converts glucose $C_6H_{12}O_6$, into pyruvate, CH_3COCOO^- (pyruvic acid), and a hydrogen ion, H^+. The free energy released in this process is used to form the high-energy molecules ATP (adenosine triphosphate) and NADH (reduced nicotinamide adenine dinucleotide).

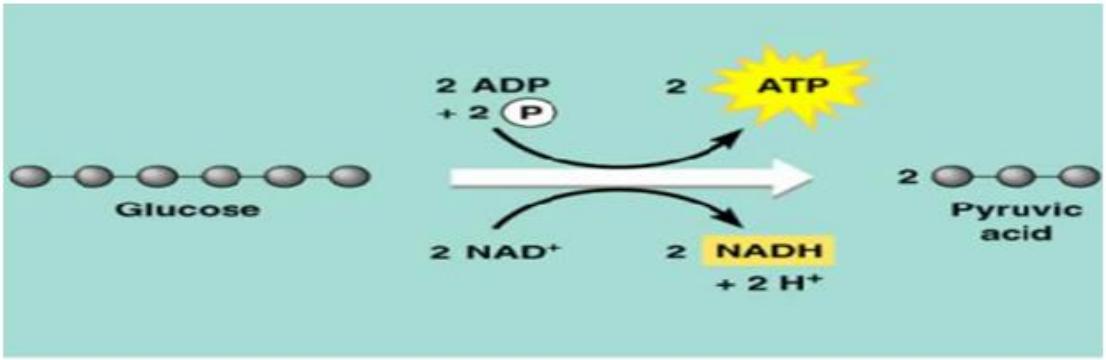


Figure (2-3): Method Glycolysis

- Gluconeogenesis: is a pathway consisting of a series of eleven enzyme-catalyzed reactions. The pathway will begin in either the liver or kidney, in the mitochondria or cytoplasm of those cells, this being dependent on the substrate being used. Many of the reactions are the reverse of steps found in glycolysis.

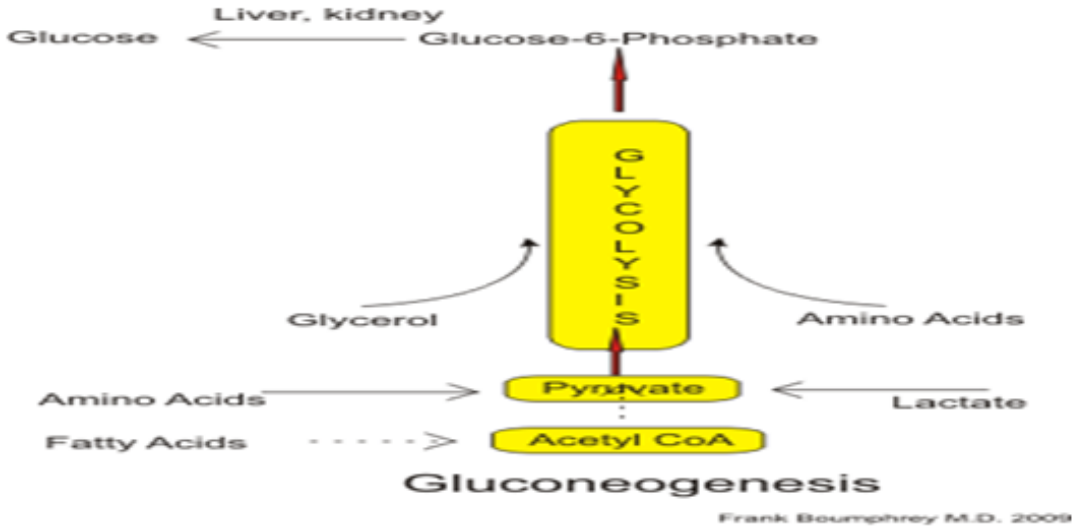


Figure (2-4) : Gluconeogenesis method

2.2.4. The importance of insulin:

- Insulin is a hormone made in your pancreas , a gland located behind your stomach. It allows your body to use glucose for energy. Glucose is a type of sugar found in many carbohydrates
- After a meal or snack, the digestive tract breaks down carbohydrates and changes them into glucose. Glucose is then absorbed into your bloodstream through the lining in your small intestine. Once glucose is in your bloodstream, insulin causes cells throughout your body to absorb the sugar and use it for energy.
- Insulin also helps balance your blood glucose levels. When there's too much glucose in your bloodstream, insulin signals your body to store the excess in your liver. The stored glucose isn't released until your blood glucose levels decrease, such as between meals or when your body is stressed or needs an extra boost of energy.[3]

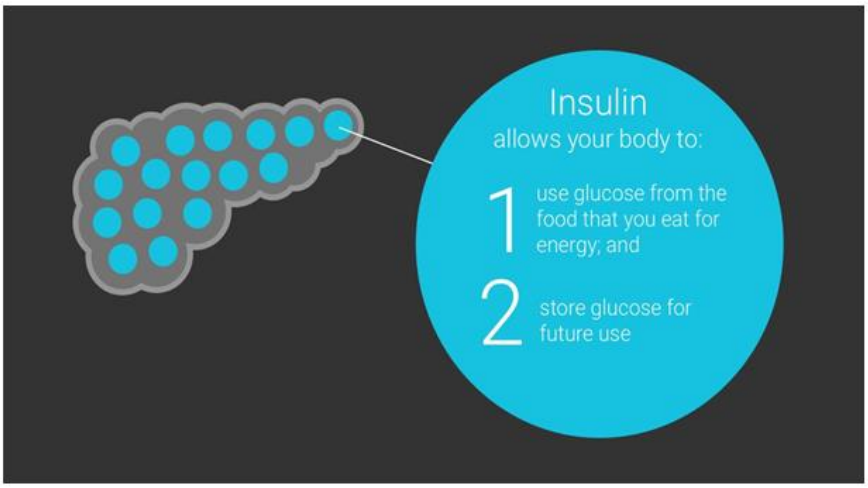


Figure (2-5): Function of insulin

What is the insulin pump? 2.3.

An insulin pump is a medical device used for the administration of insulin in the treatment of diabetes mellitus, also known as continuous subcutaneous insulin therapy. The device configuration may vary depending on design. A traditional pump includes:

- the pump (including controls, processing module, and batteries)
- a disposable reservoir for insulin (inside the pump)

- a disposable infusion set, including a cannula for subcutaneous insertion (under the skin) and a tubing system to connect the insulin reservoir to the cannula.

Other configurations are possible. More recent models may include disposable or semi-disposable designs for the pumping mechanism and may eliminate tubing from the infusion set.

An insulin pump is an alternative to multiple daily injections of insulin by insulin syringes or an insulin pen and allows for flexible insulin therapy when used in conjunction with blood glucose monitoring and carbohydrate counting [4].

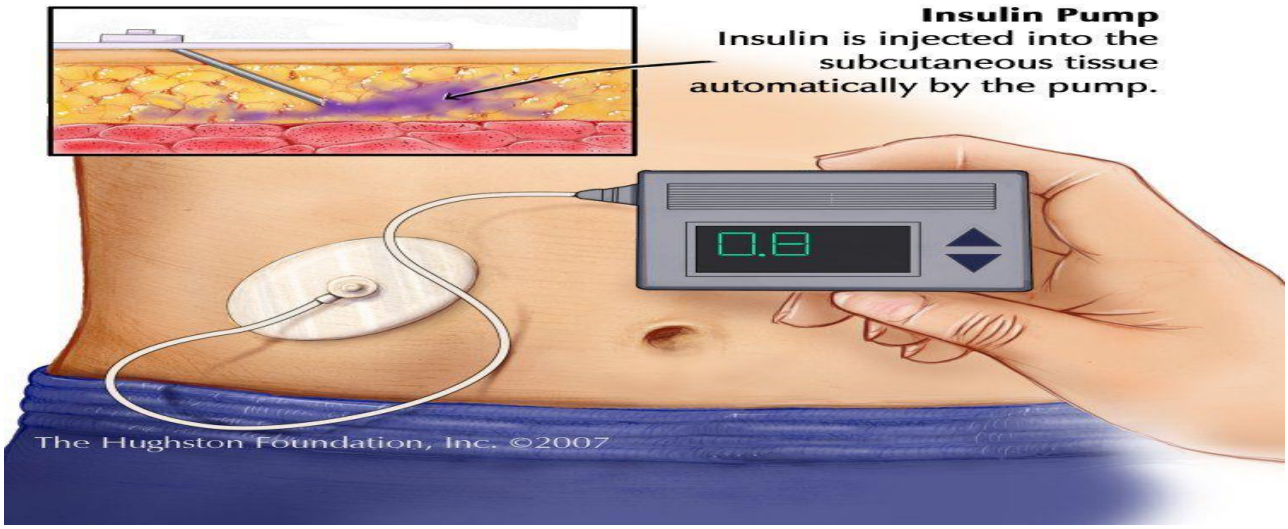


Figure (2-6) : principle work of insulin pump

2.3.1. How an Insulin Pump Work?

The device releases insulin (30 – 50 units) almost the way your body daily naturally would: a steady flow throughout the day and night, called basal insulin, and an extra dose at mealtime, called a bolus, to handle rising blood sugar from the food you eat. Doctor program the pump for both basal and bolus doses. If you eat more than normal, doctor can program a larger bolus to cover the carbs in your food. A bolus can bring down high blood sugar at other times, too.

The pump is about the size of a smartphone. Doctor attach it to your body using an infusion set: thin plastic tubing and either a needle or a small tapered tube called a cannula you put under the skin. The place where you put it in -- your belly, buttock, or sometimes thigh -- is called the infusion site. Some pumps come with inserters for easier placement even in hard-to-reach areas.

Insulin pumps use short-acting and rapid-acting insulin, but not long-acting, since the pump is programmed to deliver a small amount continuously to keep your blood sugar levels even .[5]

2.3.2. For whom it is used?

1. People who like the idea of a pump. If this is what you want, or you want for your child, and it can be used it safely, then it should be used.[6]
2. People who have frequent low blood glucose reactions.
3. Anyone who has delays in absorption of food from the stomach (gastroparesis).
4. Diabetic women planning pregnancy (Insulin is the traditional first-choice drug for blood sugar control during pregnancy because it is the most effective for fine-tuning blood sugar and it doesn't cross the placenta).
5. People who want to use the pump’s bolus calculator functions to determine insulin doses.

2.3.3. Advantage & Disadvantage

The main advantages of pump therapy are:

- Increased flexibility .
- Precise insulin delivery in smaller amounts (0.025 units minimum , pump reservoirs between 176 – 315 units) .
- Reduced blood sugar variability .
- Helps manage overnight and early morning blood sugar variation .
- Easier to handle sick days .
- Ability to cover all carbohydrates [7] .

The main disadvantages of pump therapy are:

- Risk of diabetic ketoacidosis (DKA) from pump or site malfunction .
- Risk of skin infection or allergic reaction.
- Cost – pumps are expensive (Without insurance, a new insulin pump costs about $6,000 out of pocket, plus another $3,000 to $6,000 annually for ongoing supplies, like batteries and sensors. The cost varies depending on the features, software, brand, and size of the pump).
- Having a visible medical device (if you don't want people know you have diabetes) [7].

2.3.4. An insulin pump control system:

The software controlling this system is an embedded system, which collects information from a sensor and controls a pump that delivers a controlled dose of insulin to a user.

The problem with this treatment is that the level of insulin required does not just depend on the blood glucose level but also on the time of the last insulin injection. This can lead to very low levels of blood glucose (if there is too much insulin) or very high levels of blood sugar (if there is too little insulin). Low blood glucose is, in the short term, a more serious condition as it can result in temporary brain malfunctioning and, ultimately, unconsciousness and death. In the long term, however, continual high levels of blood glucose can lead to eye damage, kidney damage, and heart problems.

These systems monitor blood sugar levels and deliver an appropriate dose of insulin when required. Insulin delivery systems like this already exist for the treatment of hospital patients. In future, it may be possible for many diabetics to have such systems permanently attached to their bodies. A software-controlled insulin delivery system might work by using a micro-sensor embedded in the patient to measure some blood parameter that is proportional to the sugar level. This is then sent to the pump controller. This controller computes the sugar level and the amount of insulin that is needed. It then sends signals to a miniaturised pump to deliver the insulin via a permanently attached needle.[8]

Closed-loop insulin pump:

Closed-loop insulin delivery, also referred to as the artificial pancreas, is an emerging therapeutic approach for people with type 1 diabetes. It is a medical device consisting of a linked continuous glucose monitor and an insulin pump. Wireless communication facilitates automated data transfer between components without the need for human intervention.

The novelty of this approach resides in the real-time feedback between glucose levels and insulin delivery, similar to that presented by the β-cell. Insulin delivery is modulated at intervals of 1 to 15 minutes, depending on interstitial glucose levels, in contrast to the pre-programmed insulin delivery that takes place during conventional insulin pump treatment.[9]

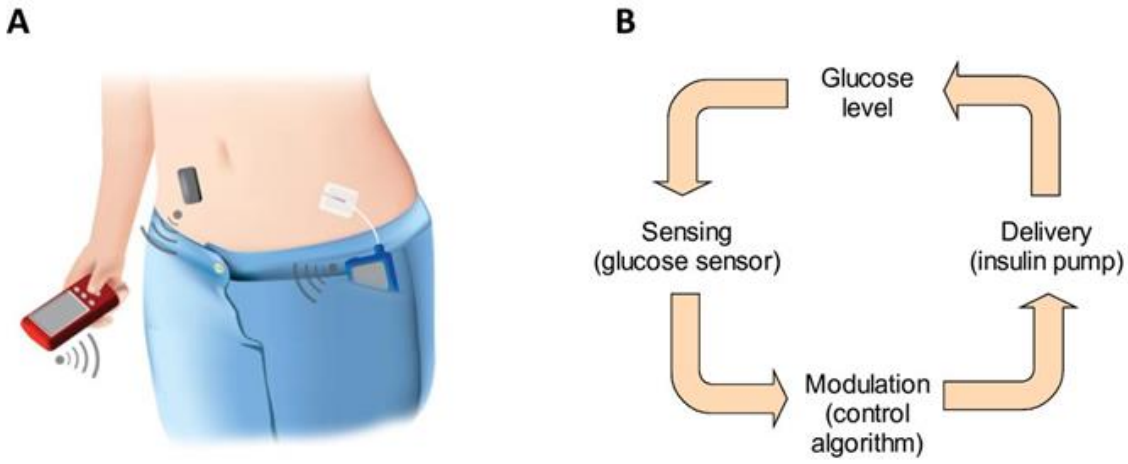


Figure (2-7) :An illustrative representation of a closed-loop insulin delivery system

a) A sensor transmits information about interstitial glucose levels to a handheld device about the size of a cellphone which holds a control algorithm and interacts with the user. An insulin pump delivers a rapid-acting insulin analog subcutaneously. Insulin delivery is modulated by the control algorithm. The communication between the system components is wireless. The control algorithm can also reside within the insulin pump.

b) The closed loop replicates the physiological feedback normally provided by the β-cell.

2.4. PID Controller for insulin pump:

The key component of the artificial pancreas is the control algorithm, which directs insulin delivery according to glucose levels while accounting for inherent measurement errors and kinetic delays. Various algorithms have been developed , but the main category is the most relevant: the proportional-integral-derivative control (PID).[9]

The PID controller represents as an insulin pump which continuously conducts the injection into the patient's body. It is set to deliver flow rates between 6.68 and 800 mU/min of insulin infusion rate.

The controller The PID controller calculates the insulin delivery based on function of the three terms:

- Proportional term (P): it adjusts the insulin delivery in response to the current glucose measured level.
- Integral term (I): adjusts insulin delivery according to the area under the curve between measured and target glucose set point (SP).
- Derivative term (D): delivers insulin in response to the rate of change of blood glucose over time.

PID controller parameters can be determined by trial and error basis within this space

Proportional feedback control can lead to reduce error to disturbances but still has a small steady state error. It can also increase the speed of response but typically at the cost of a larger transient overshoot. If the controller also includes a term proportional to the integral of the error, the error to a step will be eliminated. However, there tends to be a further deterioration of the dynamic response. Finally, adding of a term proportional to the error derivative can add damping to the dynamic response.

Table (2-1) Effect of Kp ,Ki and Kd characteristics on close loop system

Constants	Rise time	Overshoot	Settling time	Steady state error
K_p	Decrease	Increase	Small change	Decrease
K_i	Decrease	Increase	Increase	Eliminate
K_d	Small change	Decrease	Decrease	Small change

There are a general tips can help in tuning the PID controller for a given system, these tips are:

1. Obtain an open-loop response and determine what needs to be improved
2. Add a proportional control to improve the rise time
3. Add a derivative control to improve the overshoot
4. Add an integral control to eliminate the steady-state error
5. Adjust each of Kp, Ki and Kd until obtaining a desired overall response.

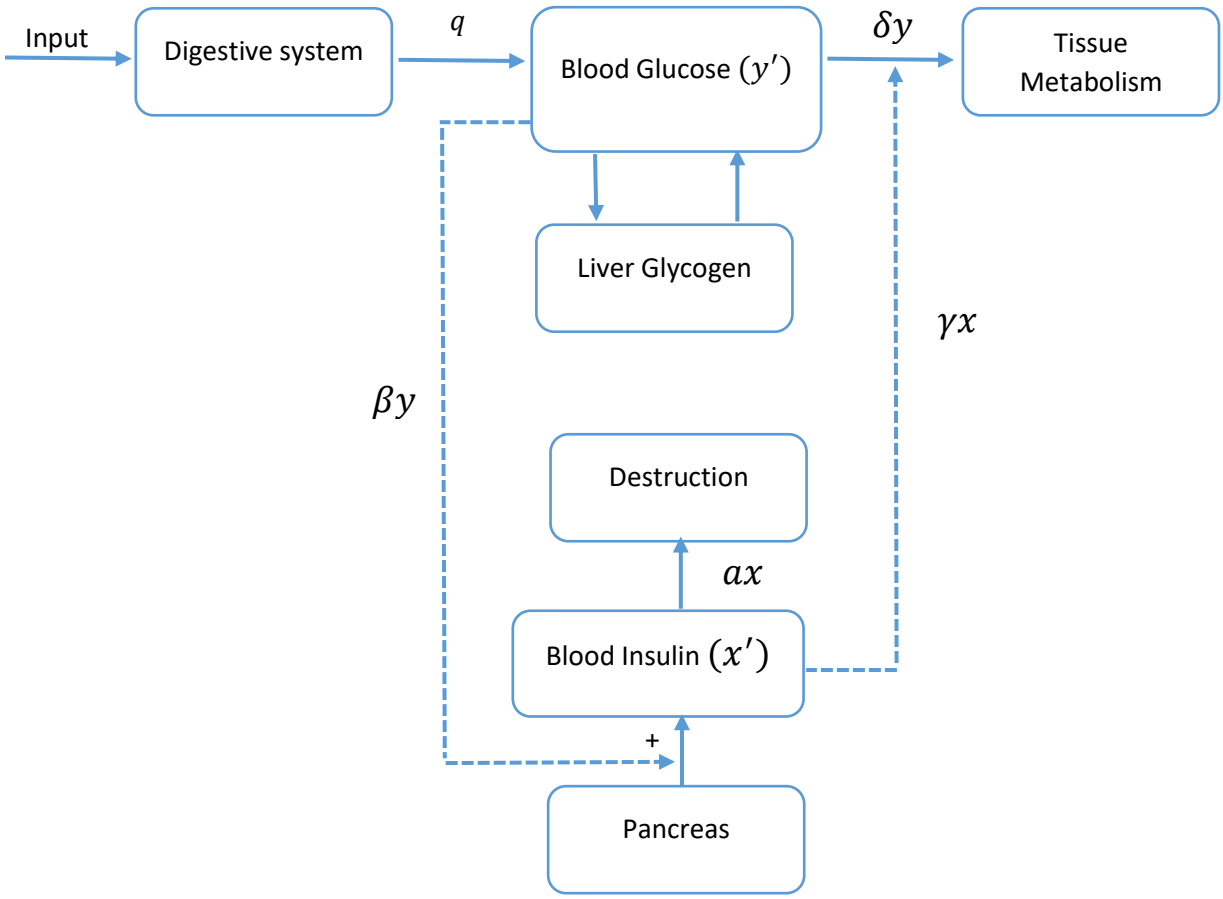


Figure (2-8): block diagram of glucose secretion

Where

q **is the glucose input due to absorption from intestines.**

δy **is the average glucose removal-rate independent of insulin.**

γx **is the net increase in glucose removal-rate, due to insulin.**

ax **is the average insulin removal-rate independent of glucose.**

βy **is the net increase in insulin release rate due to glucose.**

By considering the conservation rate of glucose and insulin in their respective compartments, we obtain the basic equations, governing BGIRS: With reference to the blood glucose–insulin system, the corresponding first-order differential equations of the insulin and glucose-regulatory subsystems are given by:

$x' = p(t) - ax + \beta y$ **……..(2.1)**

$y' = q(t) - \gamma x - \delta y$**…….(2.2)**

Where

x is the blood insulin concentration,

y is the blood glucose concentration,

p is the insulin input rate,

q is the glucose input rate,

x', y' denote the first-derivatives of x and y with respect to time.[10]

In Equations 1, let the insulin infusion rate $= 0$. Then, on differentiating Equation 2 on either side with respect to t, we get the differential equation of blood glucose response as:

$$y'' = q' - \gamma x' - \delta y'$$

$y'' = q' - \gamma(-ax + \beta y) - \delta y'$**, on substituting for** x' **from Equation 1.**

$y'' = q' + a(\gamma x) - \gamma\beta y - \delta y'$

$y'' = q' + a(q - \delta y - y') - \gamma\beta y - \delta y'$, **on substituting for** γx **from Equation 2.**

$y'' = q' + aq - y'(a + \delta) - y(a\delta + \beta\gamma)$

$y'' + y'(a + \delta) + y(a\delta + \beta\gamma) = q' + aq$ ……**(2.3)**

For p =0 , differentiating Equation 1 on both sides with respect to t, we get:

$x'' = -ax' + \beta y'$ **, for** $p = 0$

$x'' = -ax' + \beta(q - \gamma x - \delta y)$ **, upon substituting for** y' **from Equation 2.**

$x'' = -ax' + \beta q - \beta\gamma x - \delta(\beta y)$

$x'' = -ax' + \beta q - \beta\gamma x - \delta(x' + ax)$ **, upon substituting for** βy **from Equation 1.**

$x'' + x'(a + \delta) + x(a\delta + \beta\gamma) = \beta q$**…….(2.4)**

where x' **and** x'' **denote first and second time-derivatives of** x**.[10]**

The transfer function (TF) corresponding to Equation 3 is obtained by taking LPT on both sides.[11] [12]

$$s^2Y(s) + sY(s)(a + \delta) + Y(s)(a\delta + \beta\gamma) = Q(s)(s + a)$$

Thereby, we obtain (for glucose response):

$\frac{Y(s)}{Q(s)} = \frac{(s+a)}{s^2+s(a+\delta)+(a\delta+\beta\gamma)}$ ……....**(2.5)**

Similarly, from Equation 4, we get for blood insulin response:

$X(s) = \frac{\beta Q(s)}{s^2+s(a+\delta)+(a\delta+\beta\gamma)}$ **……..(2.6)**

$$\frac{X(s)}{Q(s)} = \frac{\beta}{s^2+s(a+\delta)+(a\delta+\beta\gamma)} \quad \text{.....(2.7)}$$

We can notice that the tow transfer functions are 2nd order transfer function.

The standard form of the 2nd order transfer function is

$$TF = \frac{\omega_n^2}{S^2 + 2\zeta\omega_n S + \omega_n^2}$$

$$TF_G = \frac{(s+a)}{s^2 + s(a+\delta) + (a\delta+\beta\gamma)}, TF_I = \frac{\beta}{s^2 + s(a+\delta) + (a\delta+\beta\gamma)}$$

By comparison, we can find for both systems $\omega_n = \sqrt{a\delta+\beta\gamma}$

And $\zeta = \frac{a+\delta}{2\omega_n} = \frac{a+\delta}{2\sqrt{a\delta+\beta\gamma}}$

The closed-loop transfer function of the glucose response can be expressed in the form:

$$TF_G = \frac{Y(s)}{Q(s)} = \frac{(s+a)}{(s+p_1)(s+p_2)} \quad \text{..... (2.8)}$$

The closed-loop poles:

$(s+p_1)(s+p_2) = 0 \ yields \rightarrow \ S_1 = -p_1$ **and** $S_2 = -p_2$

for $a = 0.916$**,** $\beta = 0.198$**,** $\gamma = 3.23$ **and** $\delta = 3.04$**. These being the values adopted by Bolie** [13]**.**

$$TF_G = \frac{Y(s)}{Q(s)} = \frac{(S+0.916)}{S^2 + S(0.916+3.04) + [(0.916*3.04)+(0.198*3.23)]}$$

$$TF_G = \frac{S+0.916}{S^2+3.956\,S+3.424} \quad \text{.....(2.9)}$$

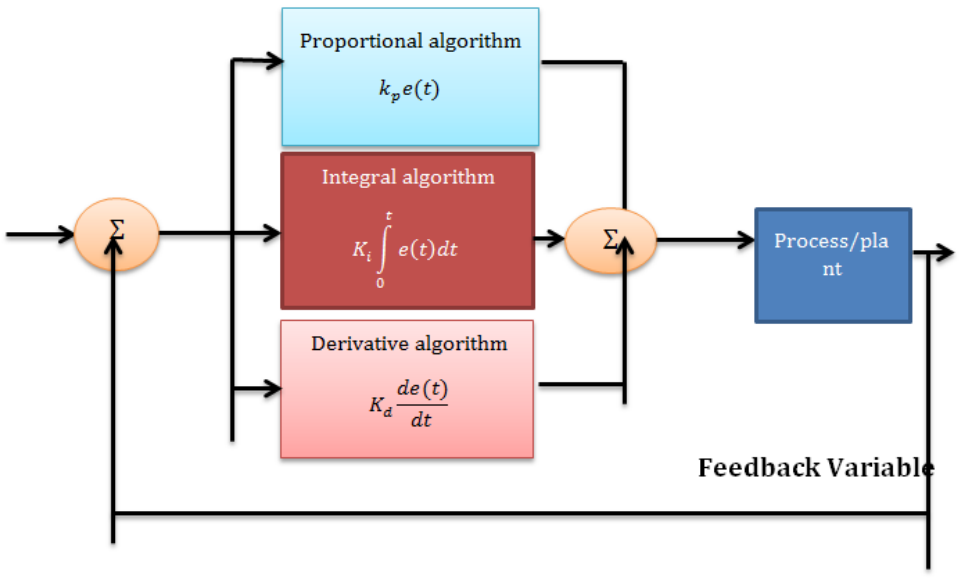


Figure (2-9): Block diagram of PID controller

The PID controller transfer function is written in the Laplace domain,:

$\frac{U(S)}{E(S)} = \frac{K_d\, s^2 + K_p\, s + K_i}{s}$ **……(2.10)**

The time-domain form of the PID controller is written as follows**:**

$$u(t) = K_p\, e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{d(t)}$$

The continuous form of controller (PID) in Eq. (10) is transformed to digital equivalent form by using z-transform :

where $s = \frac{1 - Z^{-1}}{T_s}$ then **;**

$(z) = [K_p + \frac{K_i\, T_s}{1} \frac{1}{1 - Z^{-1}} + K_d \frac{1 - Z^{-1}}{T_s}] E(z)$

$\dot{u}(k) = K_p\, \dot{e}(t) + K_i\, e(t) + K_d\, \ddot{e}(t)$ …….. **(2.11)**

$\dot{x}(t) = \frac{dx(t)}{dt} = s.x(t)$ Hence, $\dot{x}(t) = \frac{x(k) - x(k-1)}{T_s}$

Applying the Backward Difference method ,

$\frac{u(k) - u(k-1)}{T_s} = k_p \frac{e(k) - e(k-1)}{T_s} + k_i\, e(k) + k_d \frac{\dot{e}(k) - \ddot{e}(k-1)}{T_s}$ ……..... **(2.12)**

Again applying the Backward Difference method to $\dot{e}(k)$, $\ddot{e}(k-1)$,

$$\frac{u(k) - u(k-1)}{T_s} = k_p \frac{e(k) - e(k-1)}{T_s} + k_i\, e(k) + k_d \frac{\frac{e(k) - e(k-1)}{T_s} - \frac{e(k-1) - e(k-2)}{T_s}}{T_s}$$

$u(k) = u(k-1) + k_p(e(k) - e(k-1)) + T_s.k_i\, e(k) + \frac{K_d}{T_s}(e(k) - 2 + e(k-2))$.

2.5. Field Programmable Gates Array (FPGAs)

Field Programmable Gate Array (FPGA) is digital integrated circuits (ICs) that have electronics blocks which can be programmed, and these blocks have configurable interconnection between them. These blocks can be used by the designed engineer to perform huge ranges of tasks.[15]

Ross Freeman invents FPGAs at 1985 in Xilinx Company. Xilinx has been designed first FPGA in 1984 but started being in use by the engineers in 1990.

There are two kinds of FPGA:

1. One kind can be programmed for single time only and it so called one time programmable (OTP).
2. The second kind can be reprogrammed many times.

The difference between FPGA and the other devices that have internal hardwire by manufacturer is its flexibility.[16]

Every FPGA has three major components:

I. Configurable Logic Blocks (CLBs) are responsible for building the logical circuit (as programming) by the user in order to execute any Boolean functions.

II. Programmable interconnect resources are responsible for routing paths to connect the inputs and outputs of the CLB and IOB.

III. Input-Output Blocks (IOBs) are responsible for the interface between the internal signal lines and the pins of the package.

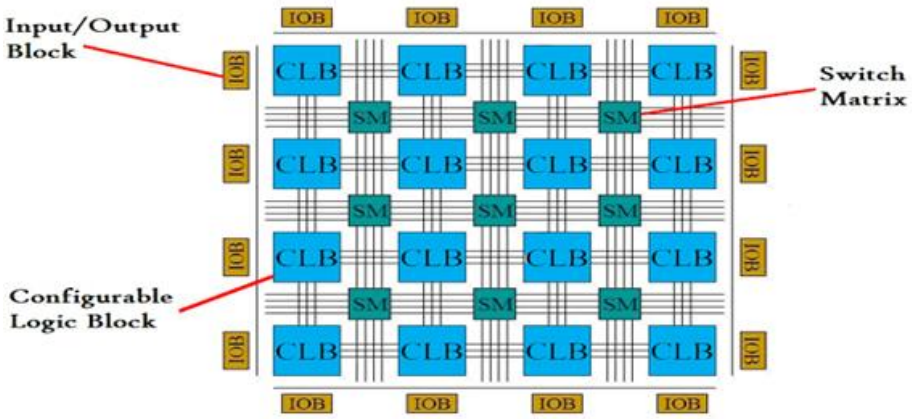


Figure (2-10) : Typical FPGA Architecture

Digital designers use hardware description languages (HDLs) to design digital systems. The design is based on the creation and use of textural based descriptions of a digital logic circuit or system.

There are two commonly used language, Very high speed integrated V-HDL and Verilog HDL. These two languages are standardized and compatible with all FPGA technology.

In order to write VHDL code efficiently, it is essential to know what data types are allowed, and how to specify and use them. VHDL contains series of predefined data types specified in IEEE 1076 and IEEE 1164 standards. [17]

Both of these hardware description languages allow the user to design digital systems by writing a program that describes the behavior of the digital circuit. The program can then be used to both simulate the operation of the circuit and synthesize an actual implementation of the circuit in an FPGA.

Once your hardware has been described you can use the functional simulator to produce waveforms that will verify your design. This hardware description can then be synthesized to logic equations and implemented or mapped to the FPGA architecture.

These days, FPGAs offer the possibility of using dedicated blocks such as memories RAM, multipliers cabled PCI interfaces and processor cores. The design of control architectures is done using CAD tools which typically includes tools for the following tasks:

- Design entry.
- Synthesis and Optimization.
- Functional Simulation.
- Physical Design.
- Chip Configuration.

FPGAs offer the rapid design cycle of programmable DSP with the flexibility and raw performance of Gate Array products. As a summary, the advantages of FPGAs include:

1. Parts may reprogram repeatedly hence to upgrade the design, there is no need to replace FPGAs, just reprogram them.
2. FPGAs are pre-tested.

3. FPGAs are a commodity part. Xilinx sells millions of FPGAs annually. This high production volume results in a lower per part cost and those savings passed on to the customer.
4. FPGAs dynamically reconfigured within the system. Sophisticated designers can build systems, which adapt to changing conditions by altering the circuit configured within the FPGA's. This re-configurable design approach is becoming more and more popular since many systems need to perform several different functions, but never all of them at the same time.
5. Design can be optimized for space and or speed.
6. FPGA process information faster than general DSP of same vintage.

Chapter Three

Fbga Based Design

3.1 introductions:

This chapter contains the design of discret insulin system by using MATLAB Simulink tool box and also it contain the design of digital PID by using Xilinx tool box via using Xilinx system generator.

3.2 design steps:

The first step:

The first step is to use decide the finite word length (number of bit) to represent the data. Twenty bit was used to represent the data of system as a singed two's complement fixed point number.

1 bit for sign bit

Bit for integer 3

12 For fraction part

The second step:

The digital PID eq. (sysd = $\frac{0.02347z^2+0.001112z-0.02236}{z^2-1.811z+0.8187}$)

is represented by using the MATLAB Simulink Xilinx tool box as shown in fig below :

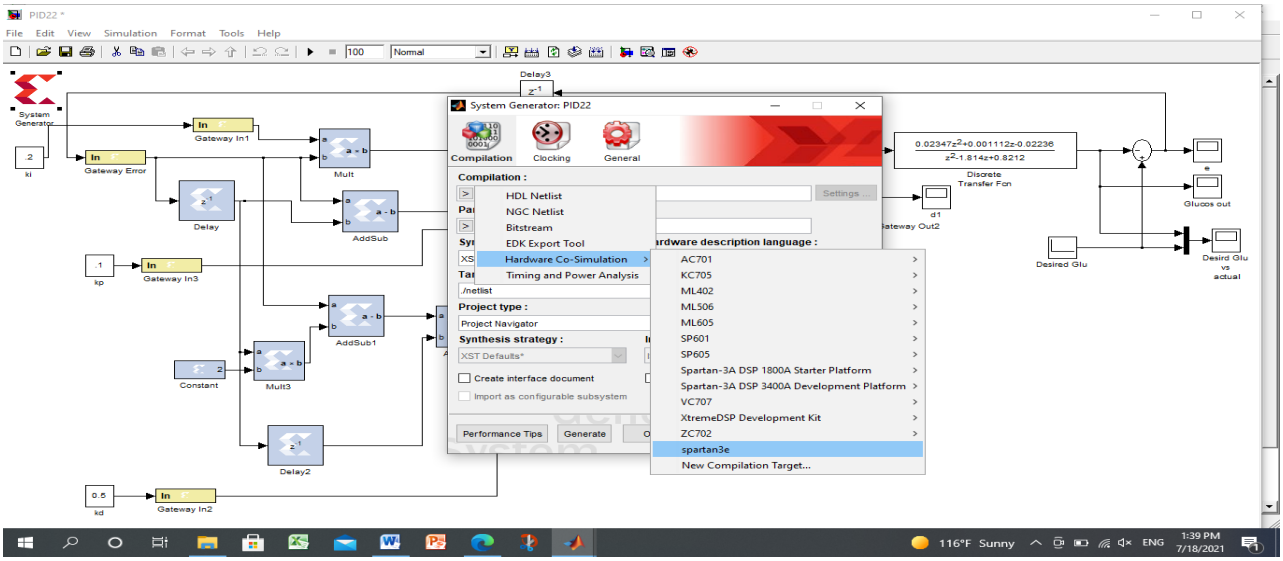


Figure (3-1): MATLAB Simulink Xilinx tool box

This model is created by using the Xilinx system generator.

The third step:

Here a discret mode for eq. ($\frac{s+0.961}{s^2+3.956\,s+3.424}$) was found as shown in eq. $\frac{0.02347z^2+0.001112z-0.02236}{z^2-1.811z+0.8187}$

By using matlab command (c2d)

Note: the sampling time is choose by using the shanwn theorem to be (0.0505) second.

Tune the PID by using try and error by using **Table (2-1) Effect of Kp ,Ki and Kd characteristics on close loop system**

Forth step:

Here the model was simulated to get the desired response. To simulate the system we need to interface the PID with the system via output gate way.

Also we need to interface the Kp,Ki,Kd value as input via input part see fig below to complete FPGA Simulink model.

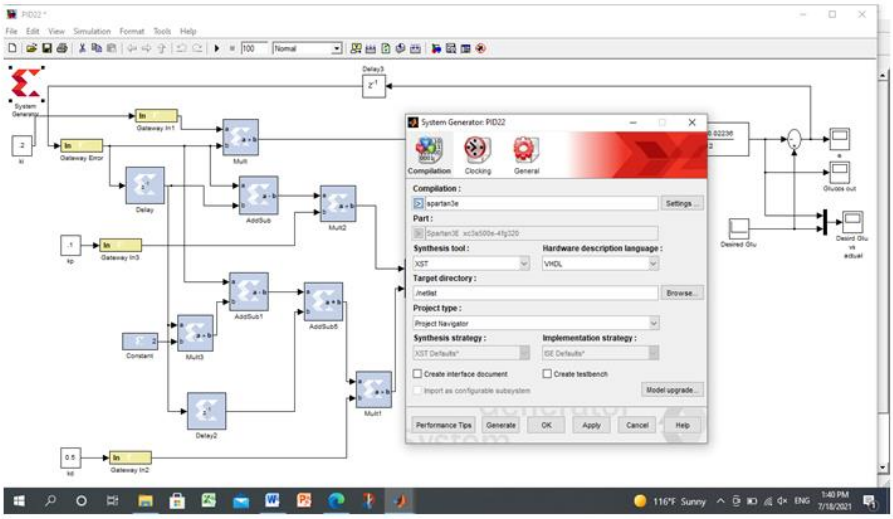


Figure (3-2) : MATLAB Simulink Xilinx tool box

Fifth step:

Used the system generator to compile the FPGA part (PID)

See fig(3-3) and fig(3-4).

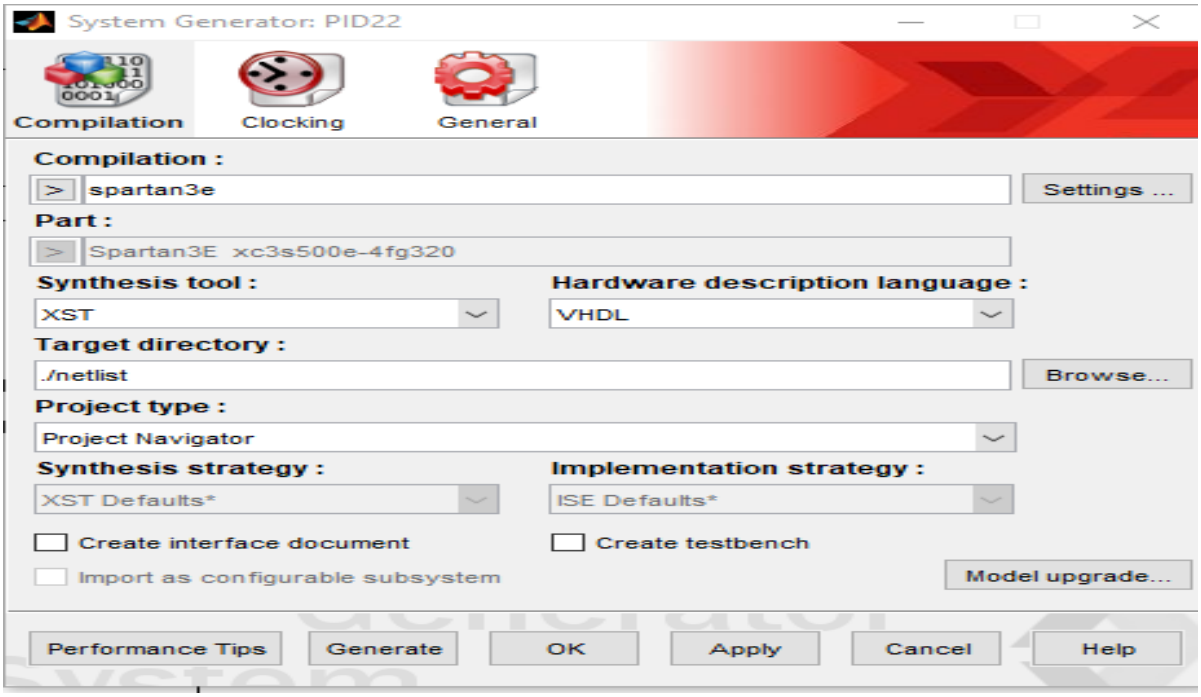


Figure (3-3): MATLAB Simulink Xilinx tool box

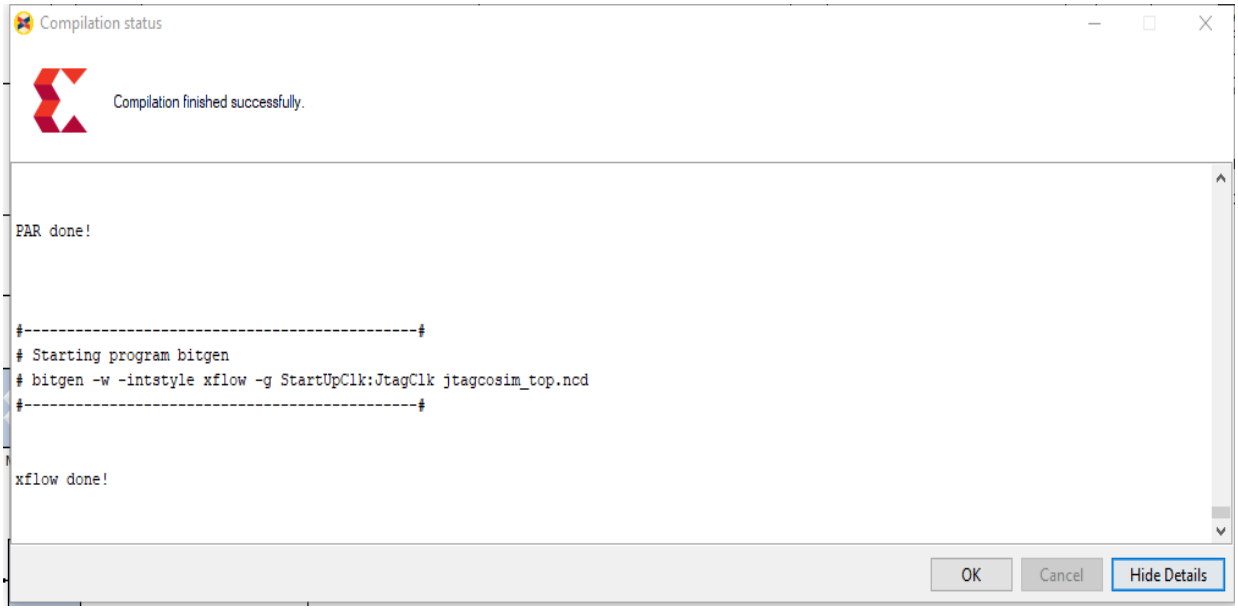


Figure (3-4) : MATLAB Simulink Xilinx tool box

Note:

In this step the generator will synthesize map and route the FPGA on spontaneous board to design summary is:

Selected Device : 3s500efg320-4

Number of Slices: 305 out of 4656 6%

Number of Slice Flip Flops: 62 out of 9312 0%

Number of 4 input LUTs: 217 out of 9312 2%

Number of IOs: 102

Number of bonded IOBs: 0 out of 232 0%

Sixth step:

JTAG Co-sim emulate will be (PID) will be read to use via FPGA kit only.

Seventh step:

Connect the system (MATLAB block).

Eighth step:

Connect the board.

Ninth step:

Run.

Chapter four

Conclutions and future work

4.1 introductions:

This chapter present the MATLAB simulation result and FPGA practical result. Also there will be a comparison between these two results.

The conclusions & the future work will be at the end of this chapter.

4.2 MATLAB simulation result

Fig (4-1) show the simulation result in this picture, there is no need to connect the FPGA board.

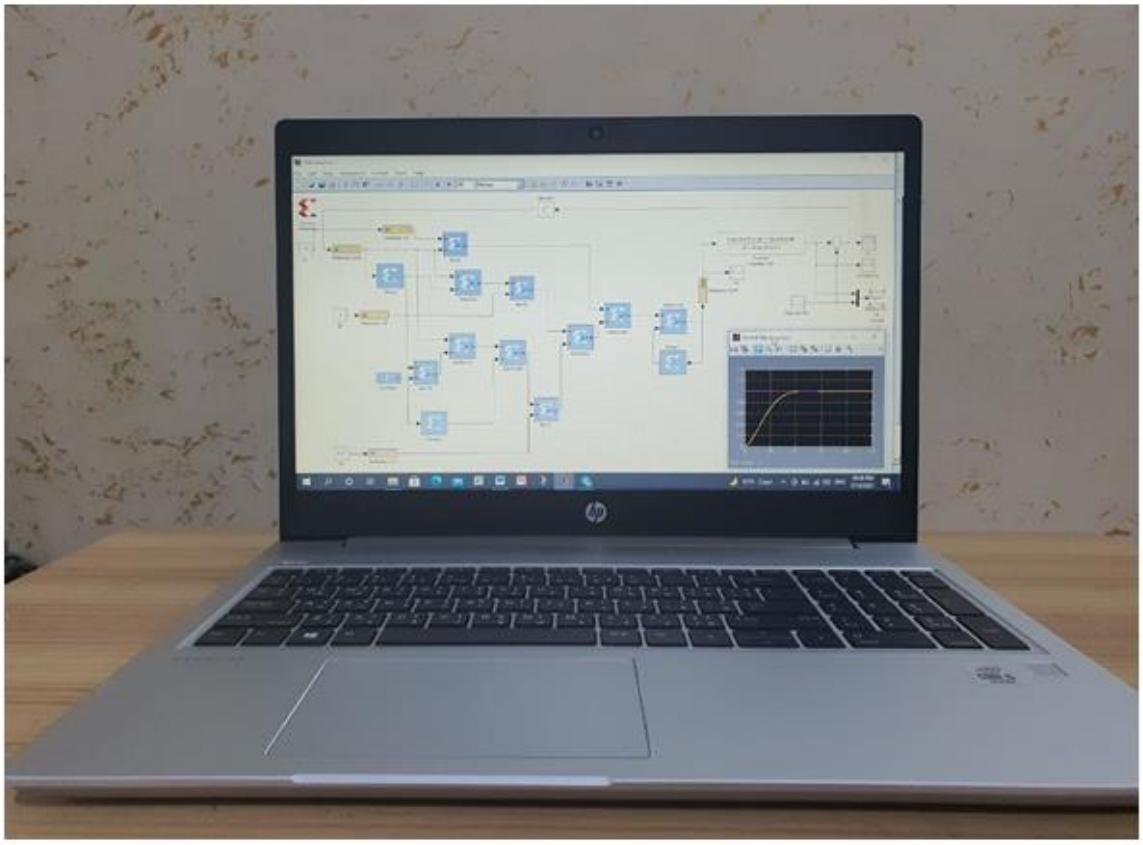


Figure (4-1) : simulation result

Fig (4-2) show open loop system:

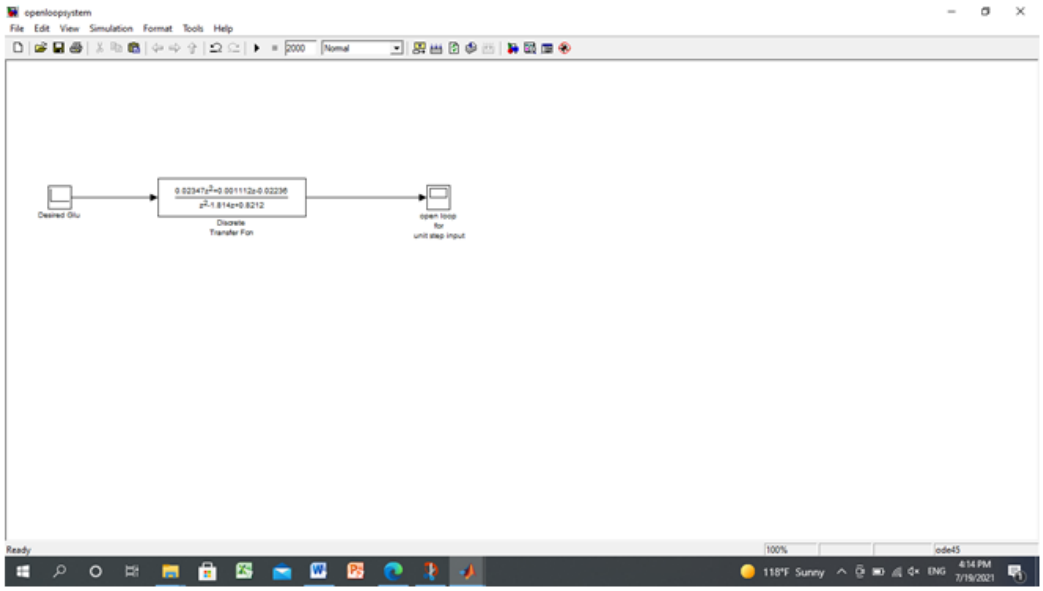


Figure (4-2) : open loop system

And fig (4-3) show the open loop response.

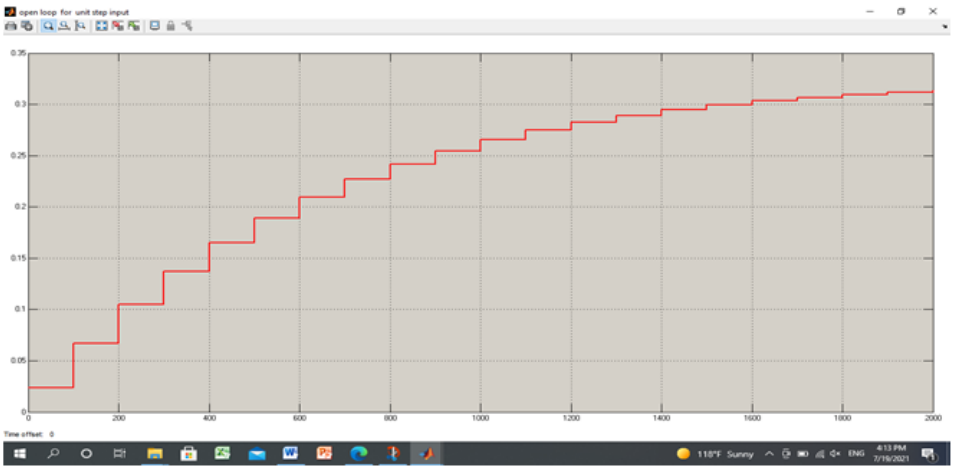


Figure (4-3) : open loop response

Fig (4-4), fig(4-5) show the close loop and close loop response respectively with KP ,Ki , Kd

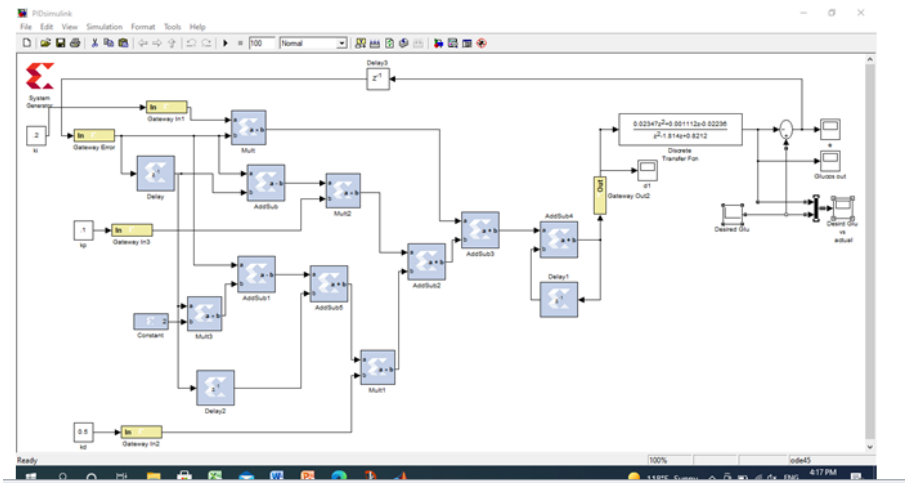


Figure (4-4): closed loop system

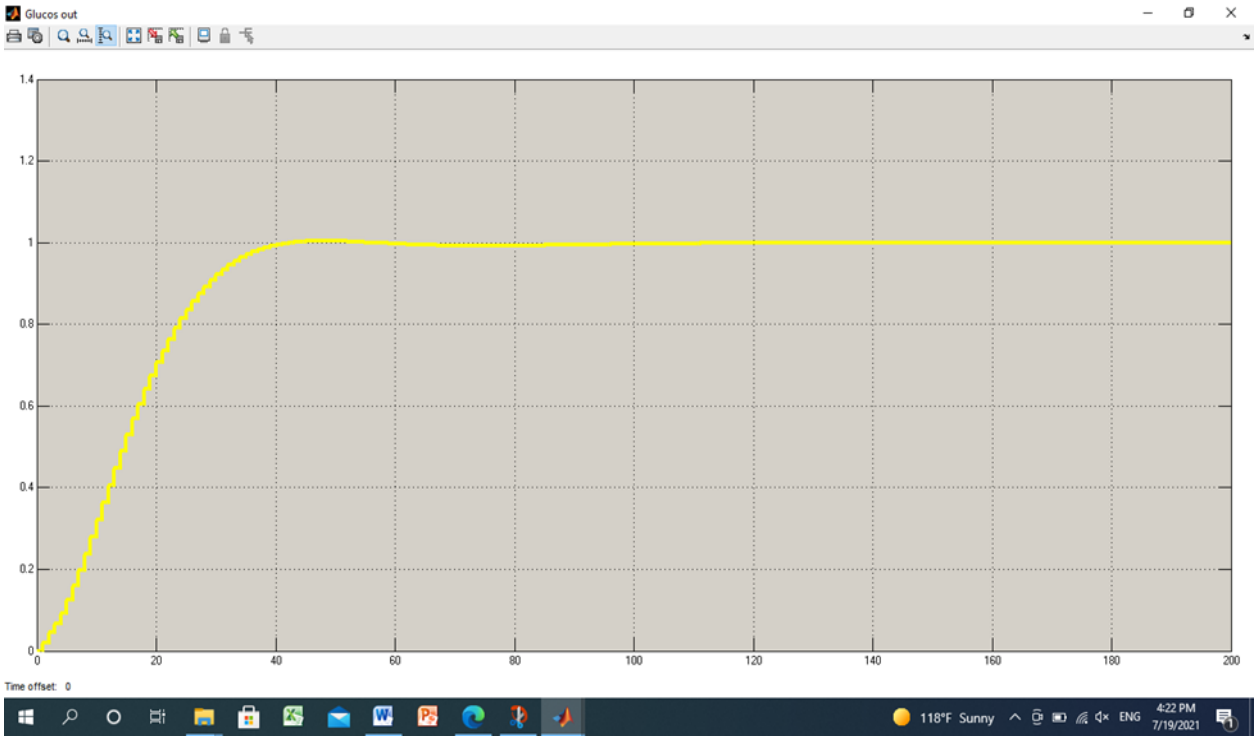
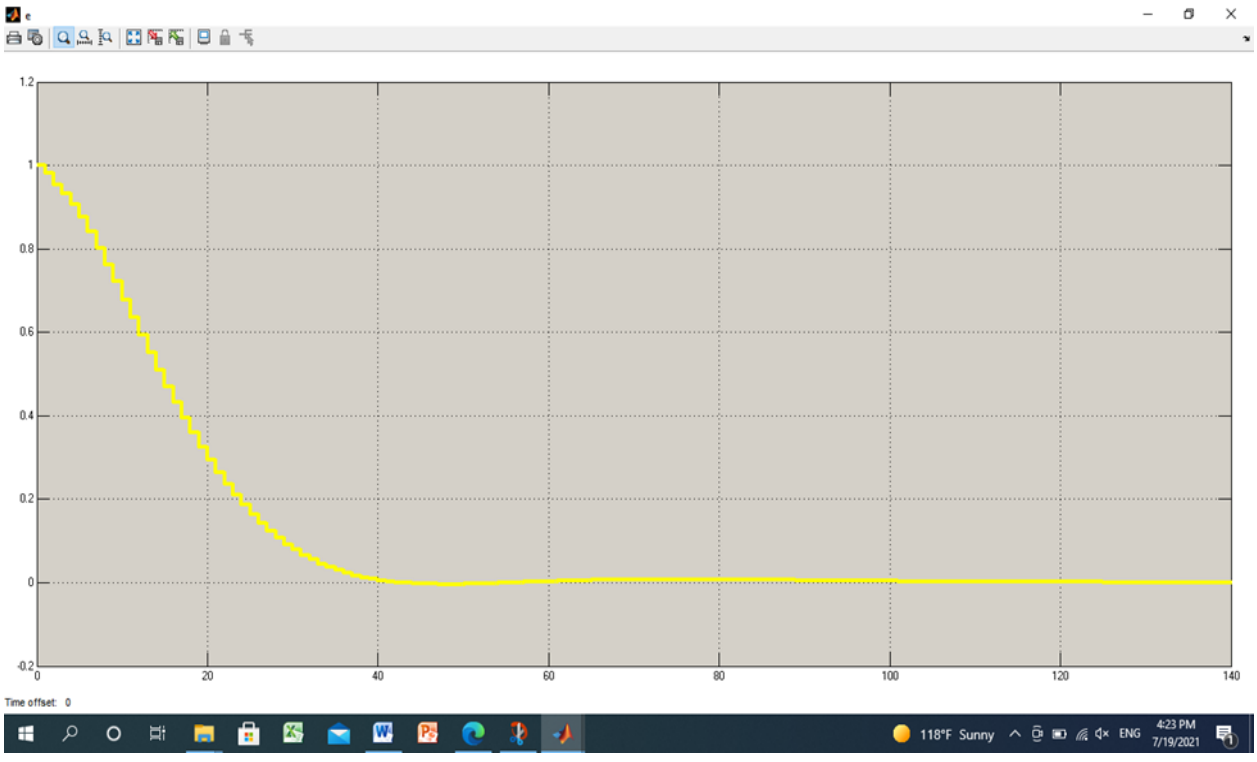


Figure (4-5): closed loop response



Fig(4-6) show the error signal :

Fig(4-7) show the actuation signed (output of PID) which represent the required amount of insulin.

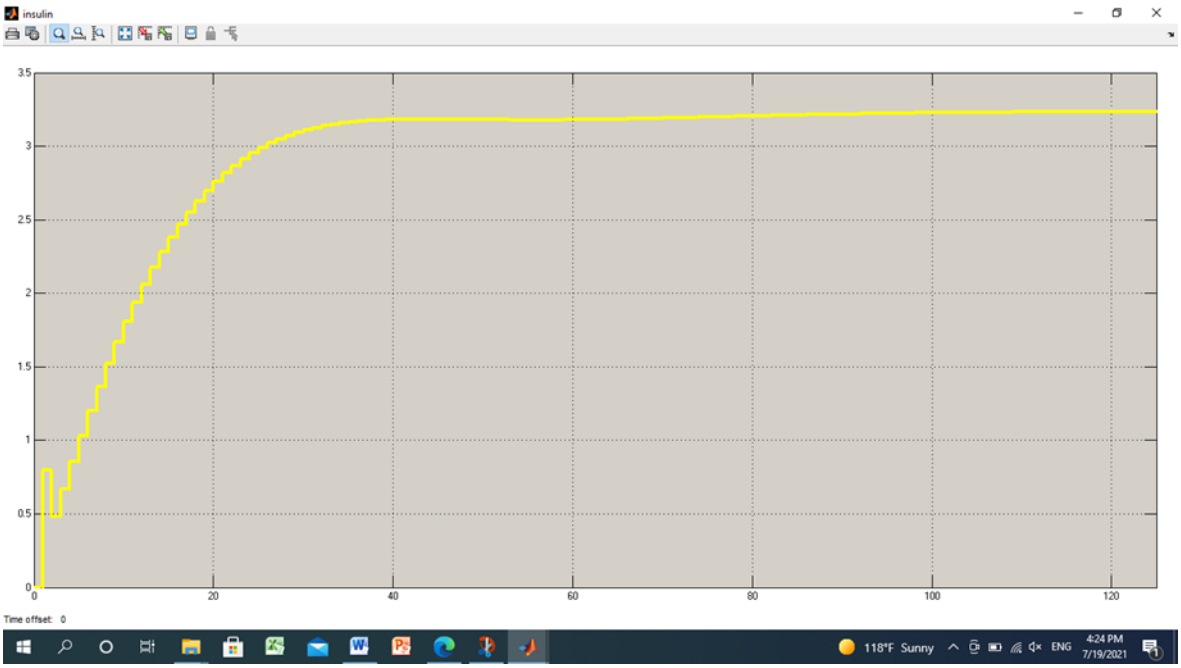


Figure (4-7) : Actuation signed

4.3 FPGA Result:

Fig(4-8) shows the FPGA board connected with the laptop and after compilation the JTAG is read to run with the board to implement the digital PID controller.

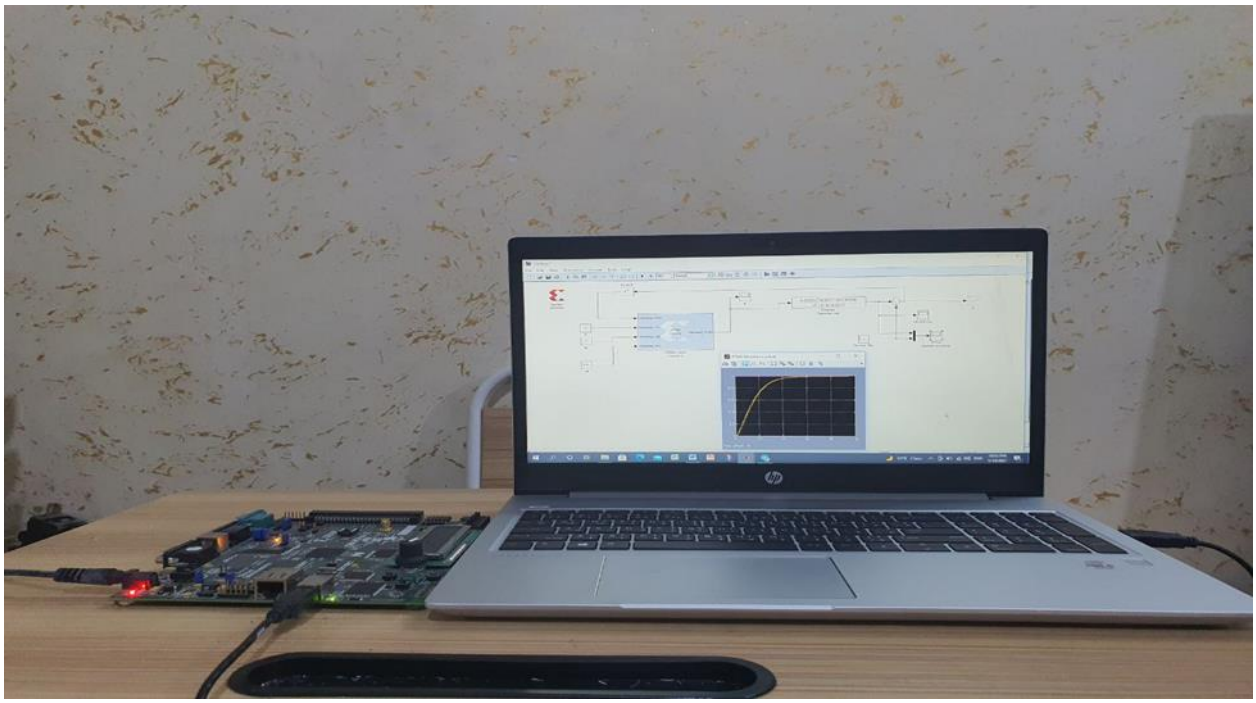


Figure (4-8) : FPGA board

Fig(4-9) show the JTAG PID

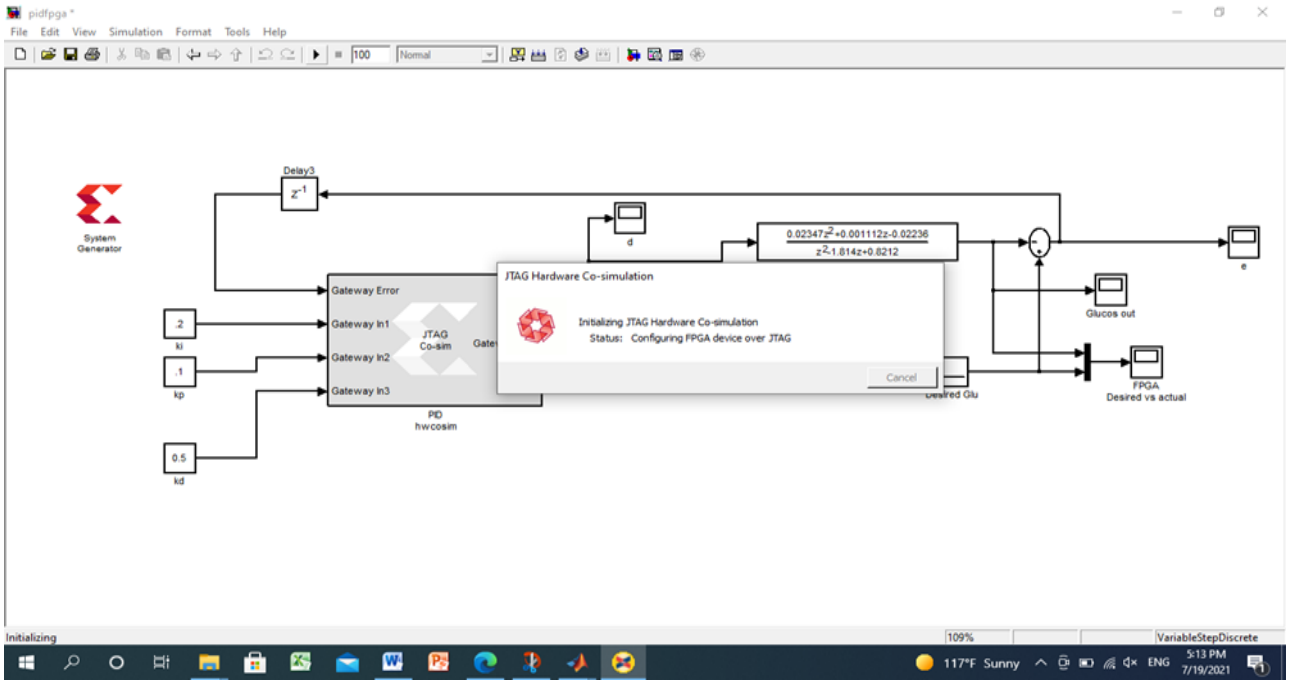


Figure (4-9) :JTAG PID

Fig(4-10) shows the system output response:

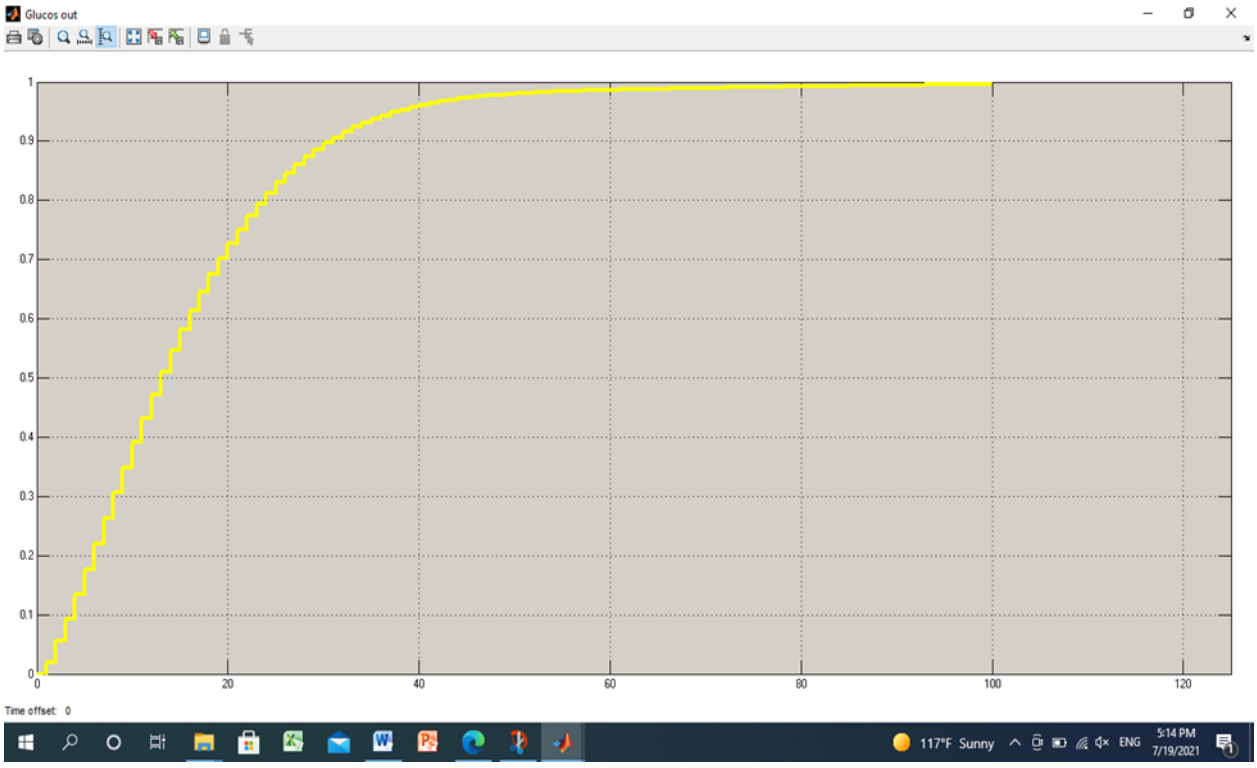


Figure (4-10) : output response

fig (4-11) show the error signal

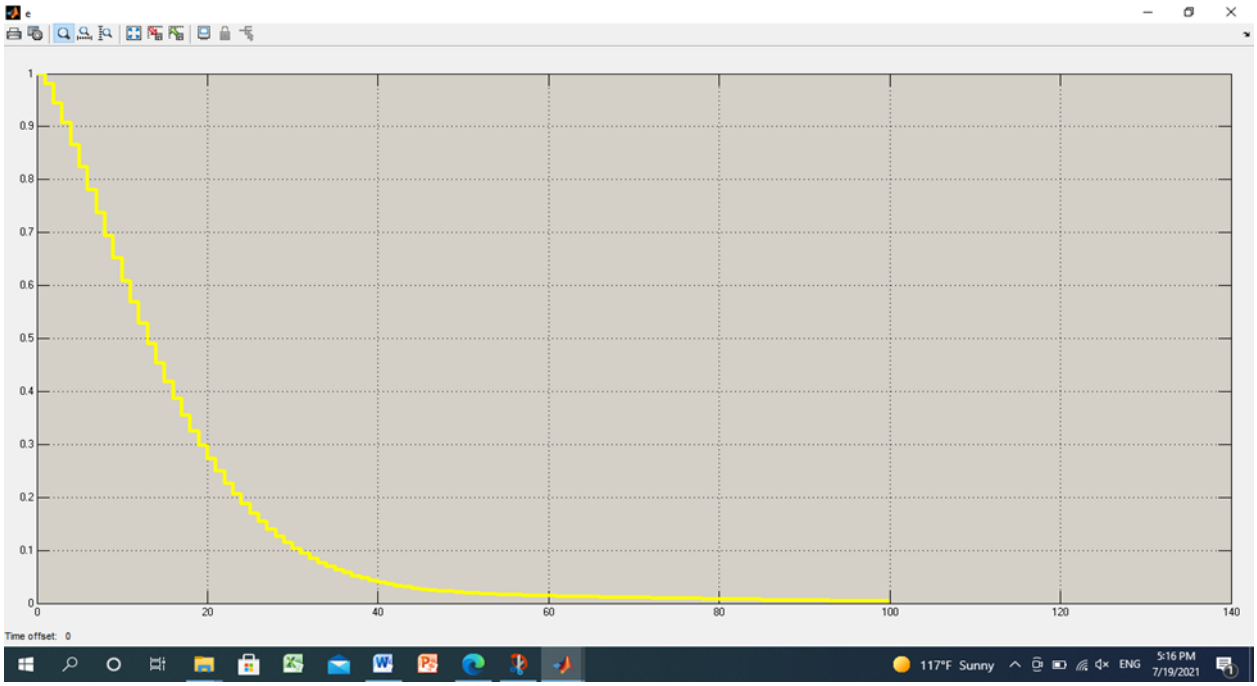


Figure (4-11) : error signal

4.4 MATLAB & FPGA

To verify the FPGA PID model with the MATLAB the two model result compared as shown in fig (4-12)

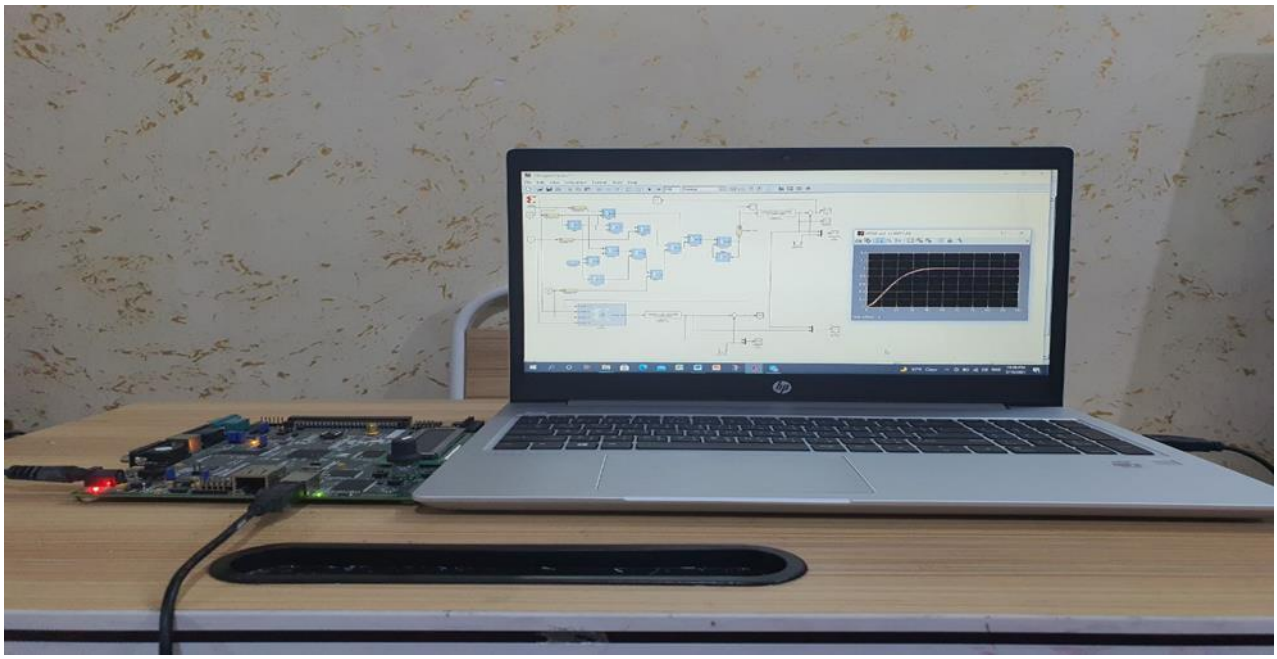


Figure (4-12) : two model result

Where the Simulink model and JTAG model appear and the board connected see fig (4-13) :

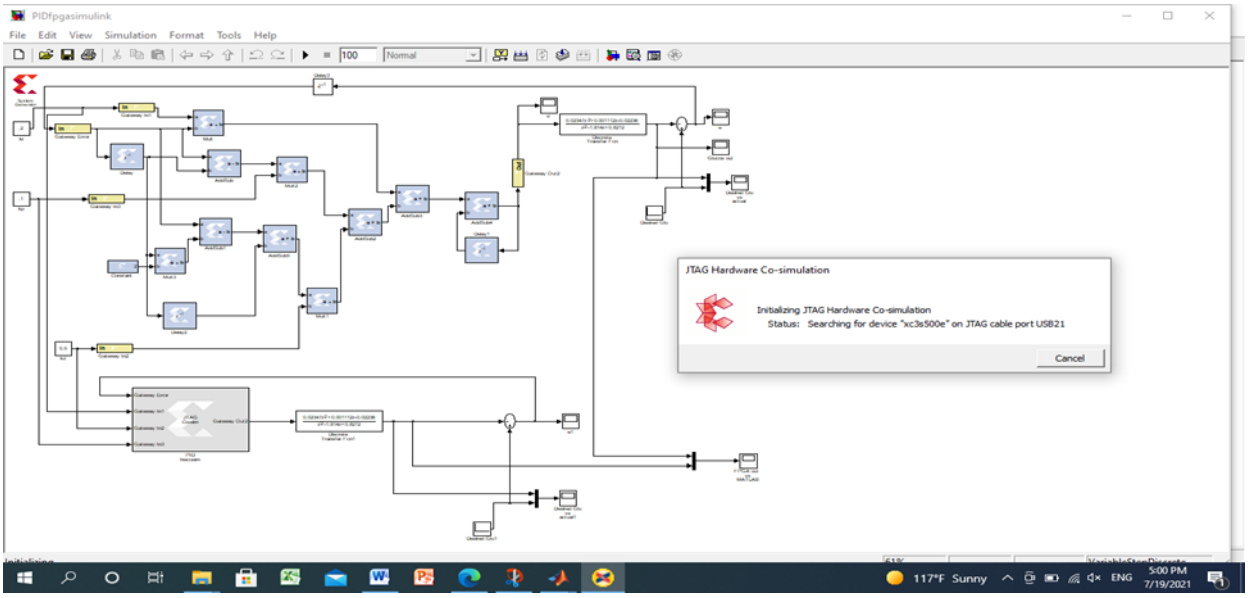


Figure (4-13) : Simulink & JTAG model

Fig(4-14) show the MATLAB Simulink response & FPGA response:

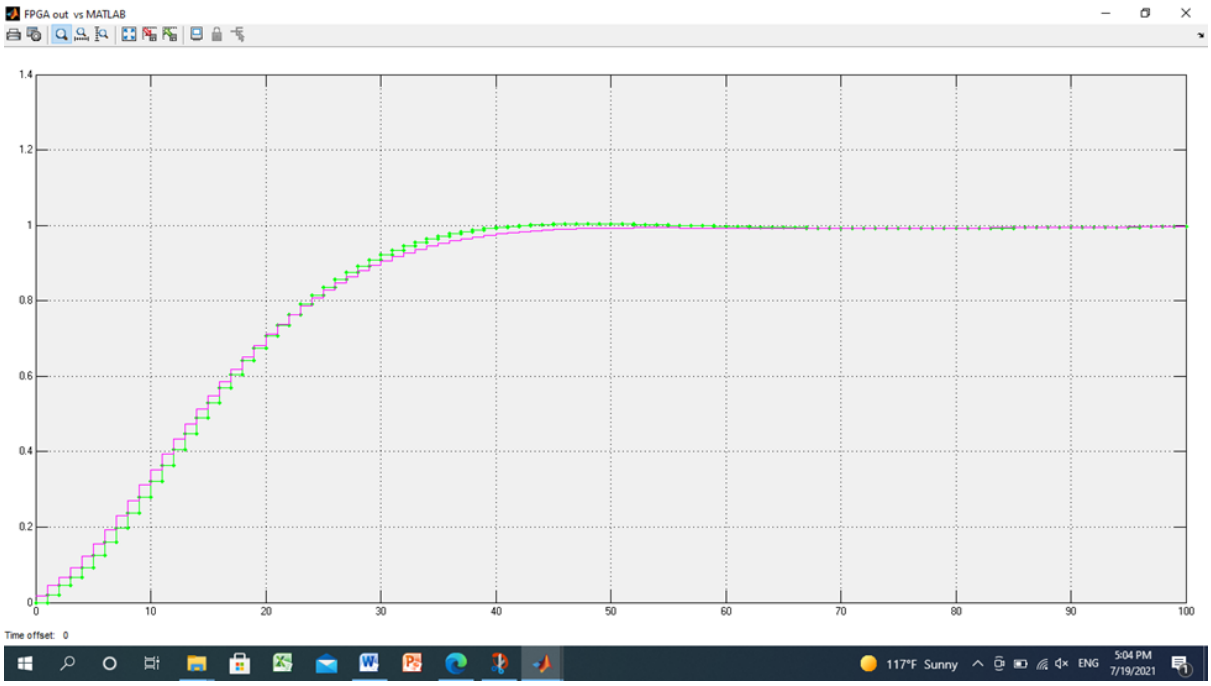


Figure (4-14) : Simulink &FPGA response

4.5 Discussion:

From the above result fig (4-15) its clear that the FPGA response approximately match with the Simulink response the mild error is due to the quantization error.

Figure (4-15) : quantization error

4.6 future work

The propose future work may be:

1. Take the disturbance in the design consideration which will be as a meal or exercise.
2. Use different transform method such as bilinea in finding the digital PID model.
3. Use intelligent auto tune method to tune the PID.

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