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Design and Developments of Thermal Control System of Electrosurgical Unit via Sensor Based on Thermometric Techniques

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Abstract: Electrosurgery has been regarding as one of the top forms of surgical interventions. This technology allows surgical procedures to be performed with high accuracy using high-frequency energy waves in order to cut organic tissue. Although there are a lot of benefits to this form of surgery, there are also dangers that originate due to the thermal nature of the procedure. Some of these issues relate to the thermal damge that can be caused by the ESU. Thus, in order to address this issue, this research proposes to use thermal sensors that can sense and read temperature fluctuations, and then by manipulating the ESG, to control the thermal output and ultimately prevent any thermal adamage to the tissue. An experiment is performed using chicken as the main tissue and experimenting with and without the controller. The results of the experiment indicated success, and that the proposed thermal control system can regulate the power and the temperature with the use of the thermal monitoring systems it has in place. The damage observed on the tissue has been observed to be little to none.

Keyword: Bipolar, Thermal Damage, Thermal Monitering, Control, PID

1. INTRODUCTION

Electrosurgery (ES) is a technique often used as a part of various types of surgery for more than 100 years. Surprisingly, electrosurgery has only been recorded as a medium for surgery in the last 50 years [1]. Surgery as a medical procedure has observed a dramatic increase within the last three decades and it is acknowledged as an incredible medical intervention. Moreover, the microvascular surgery in particular, involve the most frequent use of radio frequency instruments. ES can control the exact amount of radiofrequency of an electrical current to the delicate tissue site which is needed to be cut [2]. This technique assembles the composed electrode, which persistently advances into many dynamic researches involving different new applications [3].

In surgery, high-frequency energy and mechanical forces are regularly employed in various capacities. In each of these modalities, energy is transformed into heat to cause thermal destruction of tissue through rapid vaporization, hemostasis, coagulation or a combination. As depicted in Figure 1, an arc driven by an electrosurgical generator is established at the tip of the scalpel. The arc creates a high current density pathway in the immediate surrounding tissue. The current density then drops rapidly on its way back to the return pad which is usually situated on the patient's thigh. Thus, the current need to be dispersed to avoid alternate burn injuries on the patient as well as to complete the circuit.

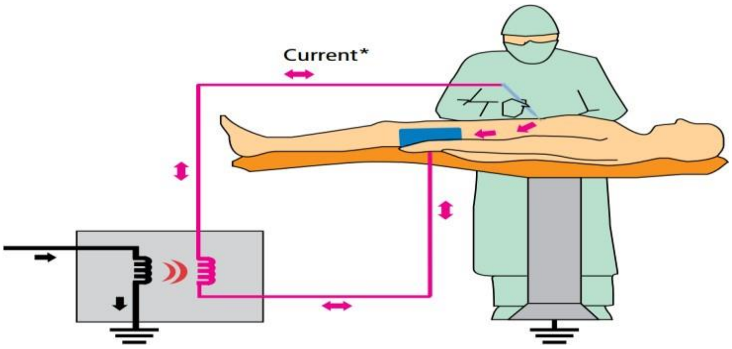

Figure 1. An Overview of Electro surgery process [4]

Control of feedback system of high frequencies for new generator that currently exist, allows an electrode to return feedback signal rapidly to varying situations that come across during cutting. Based on the characteristics of the new systems, it is worthy to develop a power supply as well as a generator and a combination of both, in order to take advantage from the strength of each system while eliminate any possible weakness. Several combinations of these characteristics should be tested, analysed, and returned to find the best configuration for the ESU. The right combination of these characteristics will utilize the benefits of both systems that will improve the Electro Surgical Unit (ESU) properties especially for cutting and coagulation. This project aimed to designing and developing a new electrosurgical high frequency generator and power supply with multiple output voltage.

Tissue burns are among the most frequent issues and complications that can occur after high frequency Electrosurgery. Following this logic, the minimization of such issue must be among the top priorities for the electrosurgical device development [5]. However, this problem has become difficult to tackle due to the variation that exists within the parameters. Parameters such as: the distance between the tissue and electrode, the position of the passive electrode, the characteristics of gas and vapour, the type and state of the biological tissue that is under the surgical process, the positioning of the operating cable, the type of instrument used for the surgery, and the wide range that exists for the output circuit impedance may change, thus affects the interaction between the current and the tissue during the dissection and coagulation.

Currently, there are several unimplemented approaches that were proposed to overcome the thermal damage issue [6-9]. One of it is the feedback control of the generator. This feedback enables ESU to respond quickly to the changing conditions encountered during cutting. The generator control method has improved the cutting performance and safety requirements of the procedures by reducing the risk that could rise from alternate site burns. This feedback control circuit decreased electromagnetic emissions and capacitive effect differences from current mainstream electrosurgical generators thus reduce unintended tissue damage and electrode drag, as well as indicating that capacitive coupling of electrosurgical energy to cannula is decreased by a significant amount. This on itself reduces the risk of alternate site burns. The data shown indicates that this type of generator would also reduce interference with other systems in the lab such as video systems. This is due to the reduced electromagnetic emissions [10]. It is critical to regulate the output power and peak voltage provided by the ESG in order to minimize unwanted thermal damage such as charring of tissue [11]. It is important to control the radio frequency and the amount of current to avoid the stimulation of neuromuscular and the risk of electrocution.

Thermal damage is one of the biggest issues in electrosurgical procedures, and although there are several methods that aim on addressing this issue, most rely on either the operator or the equipment in order to prevent thermal spread. However, there is a need for an automated technique that can not only monitor, but also control the power output, which consequently affects the temperature output of the electrosurgical electrodes, minimalizing or eliminating unintended thermal spread.

The aim of our study to design and implement a thermal control for ESU with the benefits of reducing thermal spread and effect on tissue by regulating output current and voltage shapes Section II defines the system designed with thermal sensor and design details are provided Section III presents materials and methods to describe the items used in new porotype. Section IV presents experimental results illustrating how the prototype ESG is able to produce and closed-loop regulate to a wide range of loads. Conclusions are presented in Section V.

2. RESEARCH METHODOLOGY

2.1 Proposed Bipolar Thermal Control System

The new sensor with the utilization of image processing preparing and guide warm with the end goal to distinguish the temperature and the structure of the control framework to control the temperature by controlling the electrical voltage yield of the ESG This process is depicted in Figure 3. The ESG changes its temperature continuously in order to successfully understand how ESU generator Temperature Control System works. The temperature may increase or decrease depending on the tissue impedance. In this case, temperature is being regulated by a control system, called PID controller. The optimum temperature (set point) of the process is stored in the range of 35˚C to100°C. That information is always available for some structures; which is called the comparator. This comparator will send signals to the power supply to rearrange the temperature. The output of these mechanisms will end as either a net increase or a net decrease in temperature. The electrode and tissue are sensed by a thermal receptor (thermo-receptors). The value recorded is then compared with the set point using a comparator. When the value is lower than the set point, the signals go mainly to the heat gain mechanisms while when the value is higher than the set point, the signals go mainly to heat loss mechanisms. In this way, body temperature is consistently sensed and maintain constant.

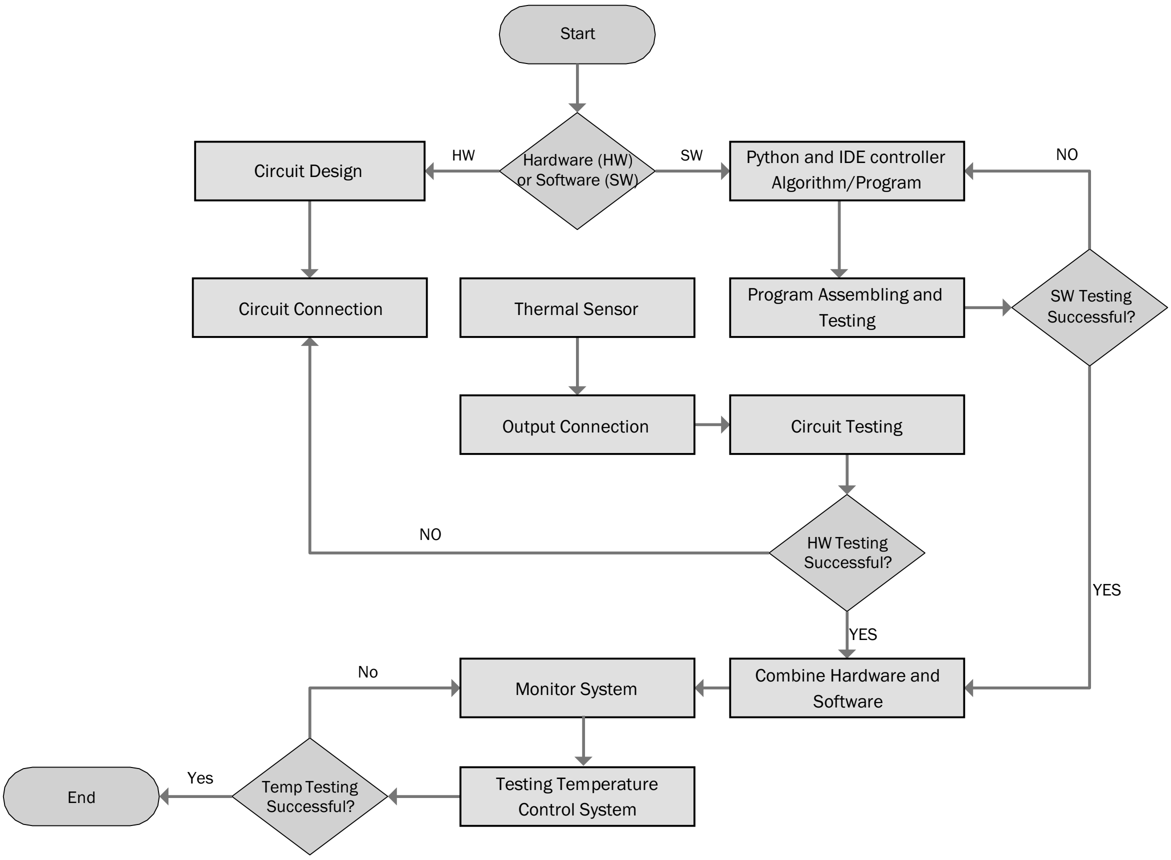

Figure 2. Proposed Thermal Control ESU Process

2.2 Thermal Camera Control System

Figure 4 depicts the data flow diagram for the thermal image identifiacation process. This process reads the temperature from the camera with aid of image processing, then the information obtained was used either to increase or decrease the voltage based on the temperature noted. The overall system describes the control condition when it is function. Thermal sensor and power supply works as two interacting entities in this process. The thermal sensor which is the thermal camera reads the information from the incision and sends the data into the process. If the information sent to the system indicates that the temperature is too high, the power supply will get instructions to reduce the voltage at the appropriate value.

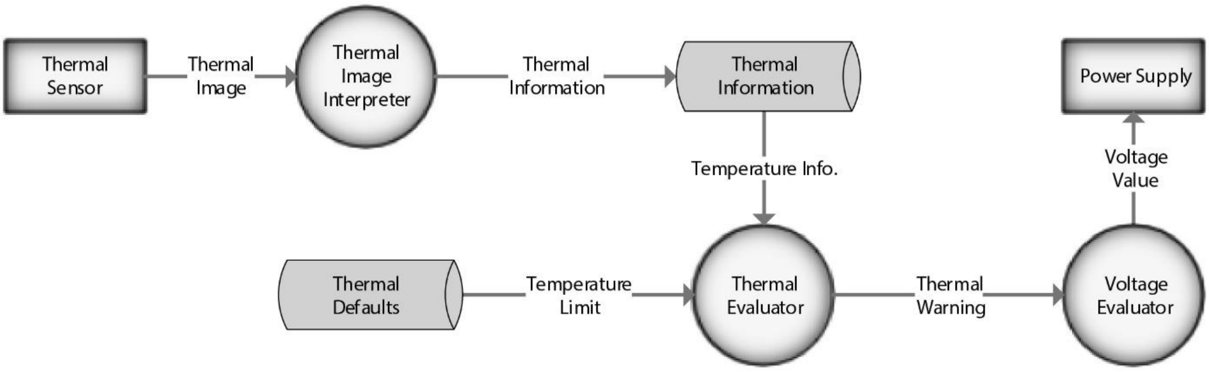

Figure 3. Thermal Image Identification Image Processing Algorithm Data Flow

When the thermal sensor sends thermal images or thermal signals to the process, they need to be converted into a meaningful information. A distinctive image does not mean anything, but the data it represents is meaningful. Therefore, thermal image interpreter is needed in the process. The data from the recorded thermal image will be interpreted and makes it useful information. This thermal information is stored in a place data source called Thermal Information, which later on can be used for thermal evaluation. Thermal Evaluator Process compares and differentiates the reality of current temperature with the existing data from Thermal Default data storage. If the temperature is considered too high, then the thermal evaluator will order the voltage evaluator to reduce the voltage. The voltage is then dynamically reduced by an interval. Since the whole system is conducted in a real time, the interval is changed according to the recorded information. If the temperature does not exceed the limit, the process will stop the voltage from changing.

2.3. Experimental Setup

The purpose of the experiment is to confirm that the thermal sensor is capable of monitoring and measuring the tissue temperature. The experiment (illustrated in Figure 5) is required to be performed twice, one with the controller and one without the controller. The temperature data is stored during each round of experiment, and compared at the end. The general idea is to compare the results of both experiments and observe the imporvements that occur when using the controller.

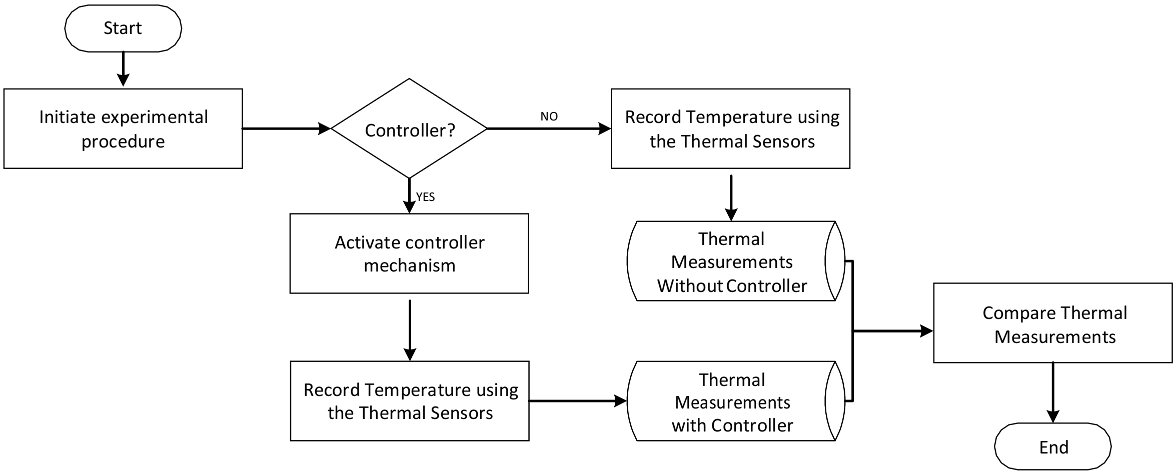

Figure 4. Experiment Setup for the Thermal Control System

2.4. Experiment Tools and Components

Figure 5 shows the laboratory setup used to animal tissue as the object. tests were carried out using two types of thermosenser, Thermocouple and thermal camera FLIR The experimental setup uses a tissue sample to simulate a surgical load. The distance of the scalpel from the tissue is controlled manually. The controller is designed to operate identically as in closed-loop results. The same tissue sample is used in all of the following cutting examples, and a simplified model of the experimental setup. The thermal camera of 8*8-pixel size is a hemisphere shape camera with radius of it centre lenses is 30 mm. Pure tungsten and high steel were used as the tool electrode. Various parameters in ESG such as open circuit voltage (*Voc*), current, discharge on-time (*Ton*), discharge off-time (*Toff*), and voltage during ESG process were considered before the experiment is executed.

This setup uses the tissue from the chicken breast area in order to simulate a surgical load. This type of tissue is used throughout the experiment in order to validate the consistency of the results. While the tissue is the same, the arcing resistance is slightly increased with each experiment. When it comes to electrosurgical experiments, the tissue choice has always been chicken, as it has several similarities to human tissue in terms of electrical conduciveness. As the maximum limit of the voltage is changed, the results affect the tissue in different ways. These effects can vary from charring (black coagulation) due to higher temperature, however if the temperature is lower, there might also be a lack of proper coagulation. In order to prevent undesired effects, the converter needs to be adjusted appropriately. Different slides of chicken are tested under different voltage output and different power settings in order to test and measure the thermal spread.

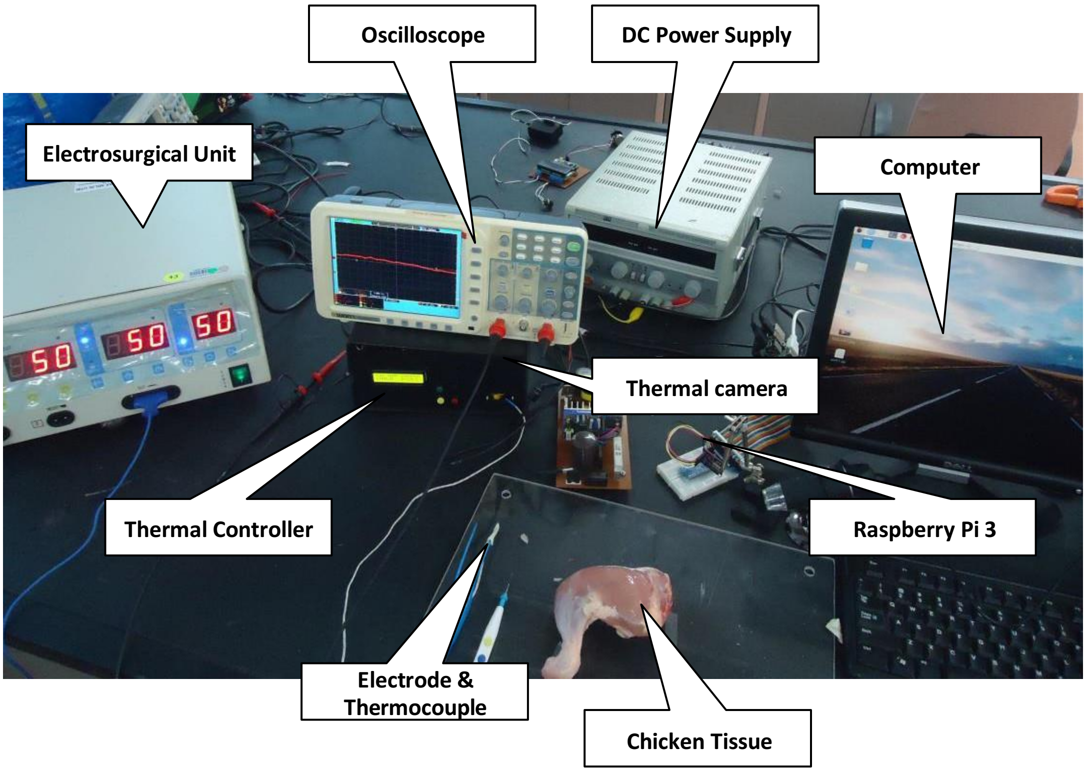

Figure 5. Experimental Setup

3. RESULTS AND ANALYSIS

3.1. Thermal Monitoring without the Controller

The following experimental images and data use the thermal camera measuring the thermal spread and heat at the electrode when in contact with tissue; and measures signal current and voltage of the system and output current. The converter is operated open loop, and the output current shape is generated by modulating the duty cycle. The first round of results show that the process is able to extract the images and process them successfully (via image processing). This means that the heat source is identified and the temperature is extracted from it (the marked green spot in the right side images). The readings performed were matched with the real tissue temperature. The extracted images and their respective temperatures are illustrated in Figure 6.

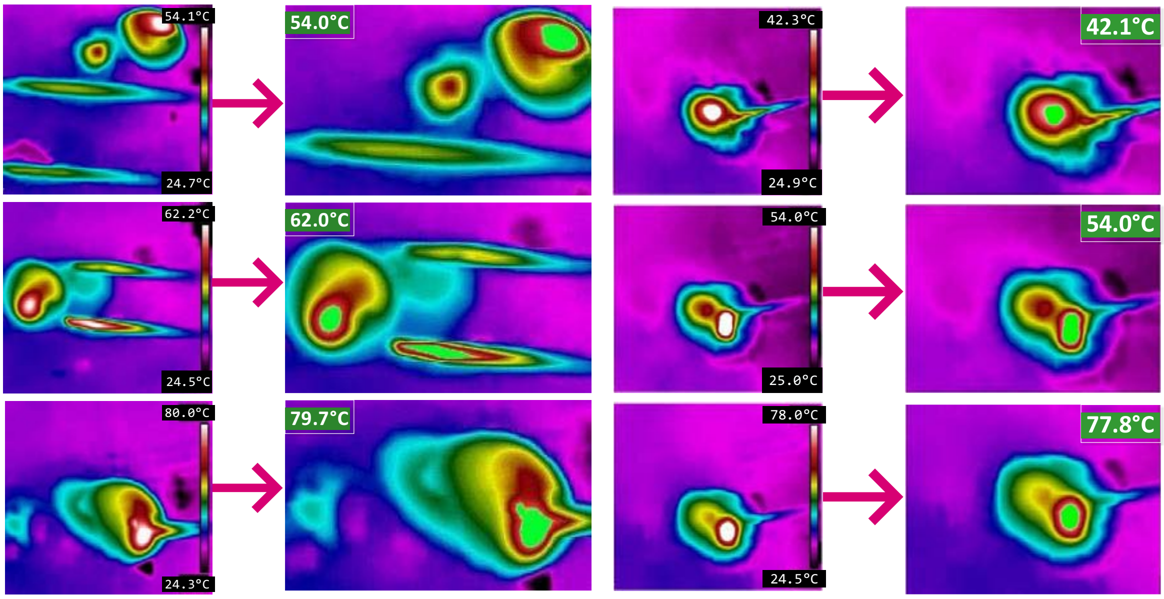

Figure 6. Thermal Image Reading without the Controller

The thermal readings from both the thermal camera and the thermocouple, as well the both settings of 25 watts and 50 watts are compared in this section. This temperature comparison consists of the experiment performed without the controller, and it simply records the information that pertains to temperature measurement on the existing control systems. The first set of charts (Figure 7 and Figure 8) compare the heating rate (°C/s) for both sensor measurement points between the two methods. The analyses showed that the temperature increasing rate significantly varied for both measurement points (camera and thermocouple sensor). The Y-axis is the temperature in Celsius, while the X-axis is the time in terms of seconds. The line chart demonstrates the narrow difference between the thermocouple and the camera temperature. Both Figures 7 and Figure 8 have their polynomial trend lines drawn as well as their fitting curve equation listed on the diagram. This indicates that the relationship between the diagrams is relatively linear. The equation is based on the average length of both camera and thermocouple values.

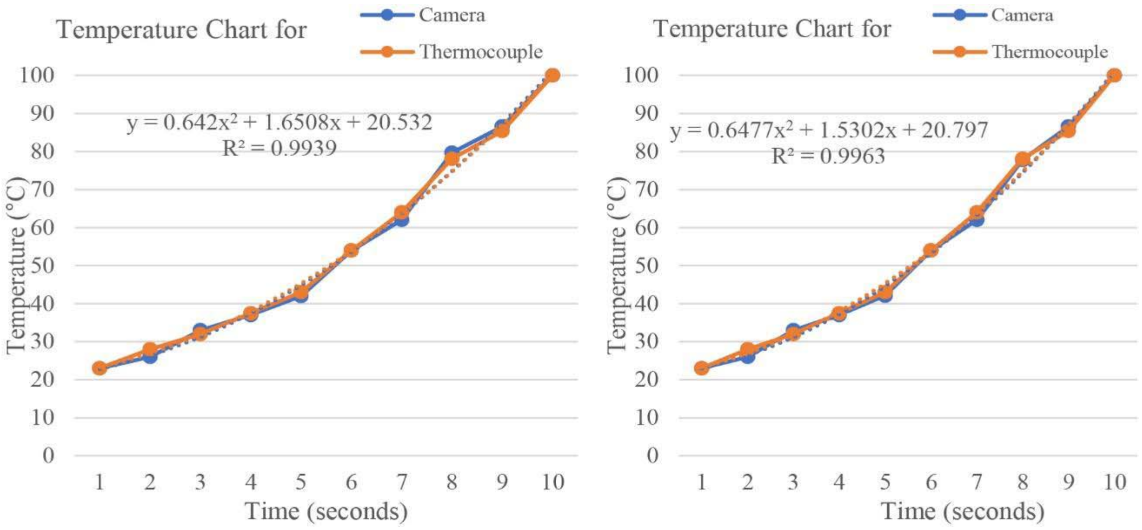

Figure 7. Temperature Readings for Thermal Camera and Thermocouple in a power setting of (25 Watts left and 50 Watts right)

Comparison tests were then carried out to compare the difference of temperature-increasing rate of the voltage output [12]. There was not that much difference between the regular thermos sensor and the infra-red mage sensor for all measurement points.Figure 8 shows a cut made in chicken using the prototype converter without thermal control system and at short duration temperature up to 80 ^{o}C. Note the complete lack of any white (coagulated thermal spread) or black (charred) tissue surrounding the incision.

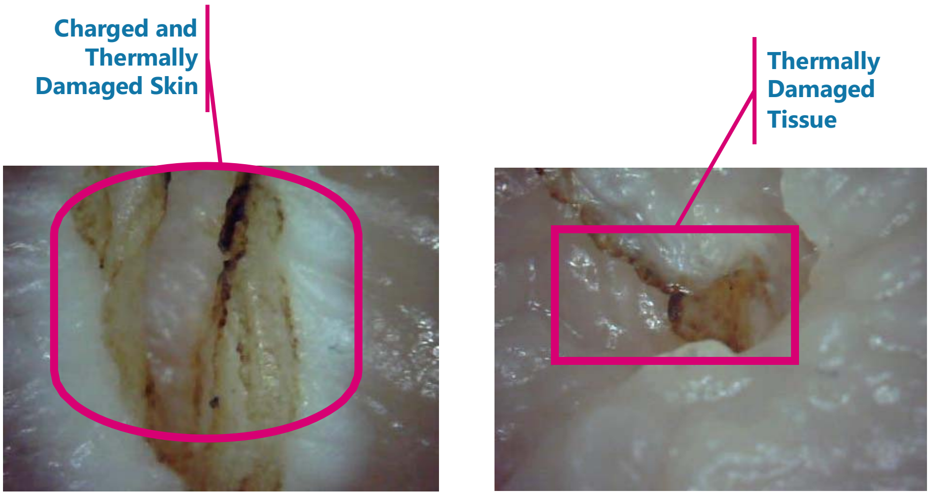

Figure 8. Thermal Damage Tissue at 80°C Open Loop

3.2. Thermal Monitoring with the Controller

The circuit is mounted on a breadboard once again and upload the next code. This second code has the PID algorithm already created. We read the temperature, calculate the error, sum the PID values and create a PWM signal on digital pin D3 that will be applied to the power supply flyback converter in second stage system. The temperature is set at between 60 °C to 100 C and use the LCD to print the set value and the real temperature. Also, set a variable set point at 60 °C for this example. Then the thermocouple's temperature value is read and with the use of the three constants, the PID is calculated. Depending on the resulting value, a PWM signal is created on pin D3 and it is applied to the MOSFET gate using driver. Figure 9 illustrates the thermal controller used in tandem with the image processing module.

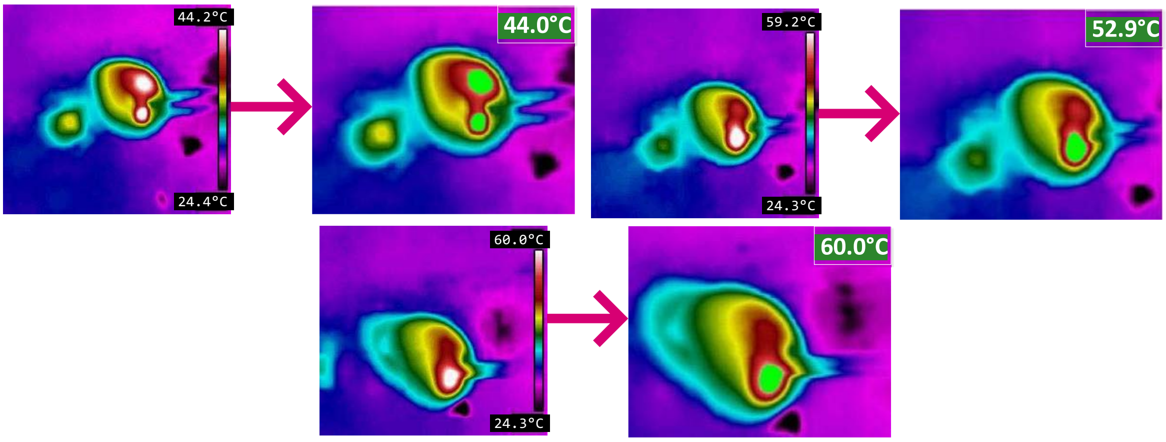

Figure 9. Thermal Image Reading with the Controller

These metrics were calculated based on python software code. The temperature and area of heated tissue, was extracted from the images collected by the thermal camera. Since the presence of the cautery pen in the thermal images might seal the view of underlying tissue, the ESG tool was removed from the image and focus on the tissue heated, and then a measurements was recorded.

The temperature comparison between the thermocouple and the thermal camera are illustrated in Figure 9. The set point temperature for this experiment was 60 °C and the proportioning band for the ESU was 5 °C. This means that the duty cycle of the ESU would be regulated between 60 °C and 65 °C. As shown in the figure, the maximum temperature of the tissue at the surface only reached 60 °C. Therefore, the ESU was controlled in this experiment. Although temperature regulation has been successfully replicated often, temperature variations are "tissue controlled" rather than feedback controlled, as a result of tissue impedance changes during heating. Figure 10 depicts the temperature over time relationships, as the temperature is gradually increasing when the temperature remains less than the set point and reaches a steady state when the set point is achieved.

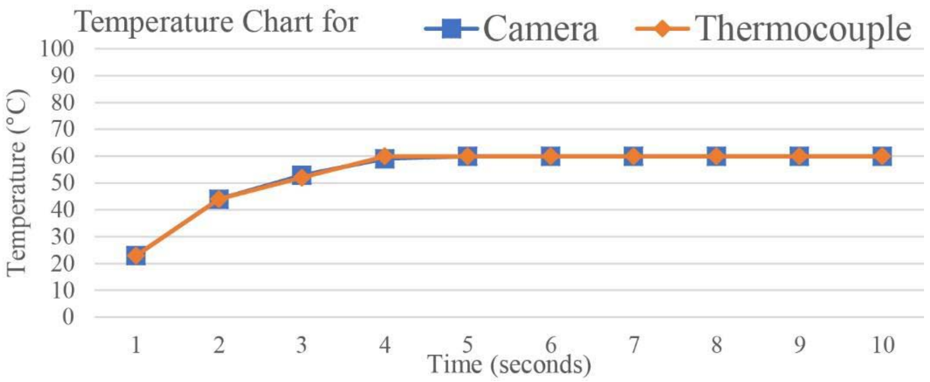

Figure 10. Thermal Sensor measurements comparison with the use of a controller between the camera and the thermocouple

Reductions in collateral tissue damage are shown in the Figure 11 by using control surgical technologies with claims that decreases damage and regulate the output are highly required across several methods comparison. Figures demonstrate that the prototype ESG performs realizing a clinically-appreciable improvement in surgical outcomes.

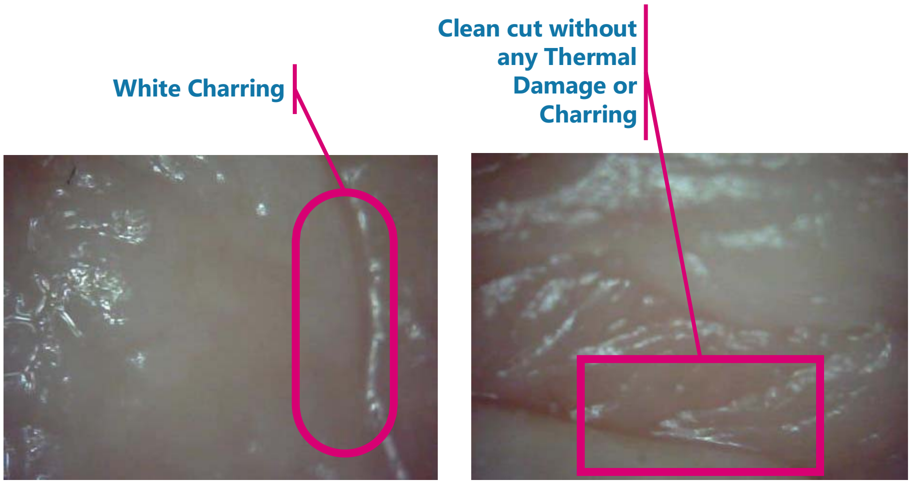

Figure 11. Tissue cutting using the thermal controller system

4. CONCLUSION

Both biomedical equipment and healthcare services are of higher quality and perform better thanks to the fast-paced innovations occurring in biomedical engineering technology in recent times. In the context of medical surgery in particular, the incorporation of the ESU machine into monopolar and bipolar electrosurgery approaches for cutting and coagulation could be advantageous. A variety of systems are supported by RF electrosurgery whilst ensuring security and viability and preventing carelessness that could result in unwanted damage to tissue.

A digitally controlled is proposed as the basis for a flexible, high-performance electrosurgical generator (ESG). Using voltage switched devices, the converter is capable of high-frequency switching with wide-bandwidth control loops supporting output voltage and power shaping across a range of output frequencies and across loads associated with electro surgery. Experimental results show both open-loop (with no control and closed-loop (with control) results. Open-loop results demonstrate the flexibility in output current shape and frequency, providing a platform for the exploration of new clinical results. Closed-loop results are for a 100 kHz constant AC reference temperature. The magnitude of the temperature reference is set by the power reference, and is calculated at the start of each period. The magnitude of the reference temperature is such that the power is adjusted instantaneously to changes in the output load. The closed-loop results are for fixed power resistors, and sample tissue cuts. The resistance values are representative of the range of resistances seen during electrosurgery. The results are given for thermal control ESG prototype operating from ±400 V with 100 kHz frequency, capable of providing up to 50 W to a load range 100 Ω to 4000 Ω.

Ultimately, the results indicate that with the use of an image processing enhanced thermal controller, it is possible to prevent thermal damage to the tissue. This type of controller can entirely eliminate the human error aspect that can cause thermal damage due to over exposure to the organic tissue.

Acknowledgements

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