THE DEVELOPMENT OF SEMI-AUTOMATED RADIOPHAMACEUTICAL DISPENSER USING REAL-TIME VIDEO PROCESSING

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This thesis presents the development of a semi-automated radiopharmaceutical dispenser using real-time video processing. Typically, a fully-automated radiopharmaceutical dispenser is expensive while a manual dispenser is harmful to operators due to radiation exposures. In the proposed system, the video camera sends the real-time video signals of the [^{18}F]-Fluorodeoxyglucose ([^{18}F]-FDG) volume in a 5-ml syringe to a computer and the volume detection is subsequently performed through video processing using MATLAB. Air is slowly pushed through an extension tube from a micro air pump to the [^{18}F]-FDG vial until the 5-ml syringe plunger is moved to reach the [^{18}F]-FDG required volume automatically. The computer subsequently displays an automated calculation volume of [^{18}F]-FDG for the operator that help a better vision of the volume of [^{18}F]-FDG and therefore a one-time operation is sufficient. The proposed system offers a potential alternative to high-cost commercial radiopharmaceutical dispenser achieving a high precision and reducing operator's radiation exposure.

Graduate school	Student's signature………..……………..……
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Chapter 1
Introduction

1.1 Background

Nuclear medicine is a medical specialty that includes applications in radioactive substances in disease diagnosis and treatment processes. The [^{18}F]-Fluorodeoxyglucose (2-[fluorine-18] fluoro-2-deoxy-D-glucose: ^{18}F-FDG), which is also commonly abbreviated [^{18}F]-FDG and generally utilized Positron Emission Tomography/Computed Tomography (PET/CT). Radiopharmaceutical is regularly prepared using an automated synthesizer. Uptaking the [^{18}F]-FDG by human tissues is an indication for the tissue uptake of glucose that is closely correlated with certain types of tissue metabolism [1]. Consequently, the PET/CT scanner can proceed either two-dimensional or three-dimensional images of the distribution of [^{18}F]-FDG throughout the patient body after the injection of [^{18}F]-FDG. The PET/CT images are used to staging, restaging, planning and monitoring therapies in various cancer patients, including uterine cancer. Figure 1.1 illustrates a 66-year-old female with endometrial cancer with uptake on [^{18}F]-FDG using hybrid PET/CT systems [2].

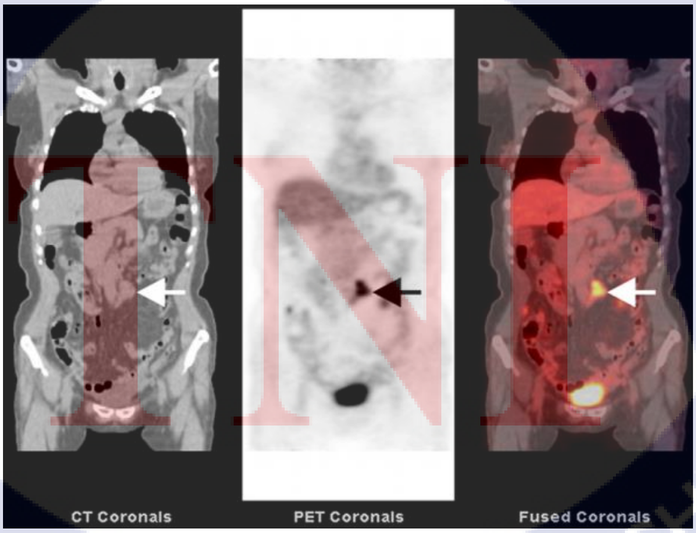

Figure 1.1 A 66-year-old female with endometrial cancer and PALN metastases (arrows) on FDG PET/CT images [2].

In the preparation process of the [^{18}F]-FDG, nuclear medicine operators such as pharmacist, nurse, chemist and doctor would certainly receive a radiation burden to the whole body and hands resulting from preparing radiopharmaceutical doses and also administration of patient doses and contact [3]. As multiple doses of [^{18}F]-FDG are dispensed from a single production over eight hours, an automated dispenser is needed to reduce the operator's radiation exposure [4]. Despite the fact that numerous automated dispensers are commercially available for [^{18}F]-FDG that are available in the form of vials or syringes, those automated dispensers are relatively costly.

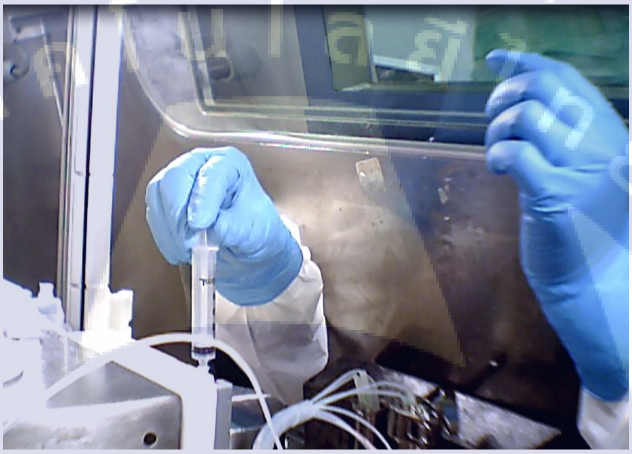

Figure 1.2 Manual dispensing.

However, the preparation of [^{18}F]-FDG in practice in many hospitals are using manual operation for small amount of [^{18}F]-FDG dispenser for economic reasons. In the case where manual operations are considered, there has been a report of a simple device for dispensing [^{18}F]-FDG from Jong O Park and et al. [5] that realizes the vial-to-vial and vial-to-syringe technique using an airflow to control the volume of [^{18}F]-FDG in order to decrease chances to receive a radiation exposures to the whole body and hands.

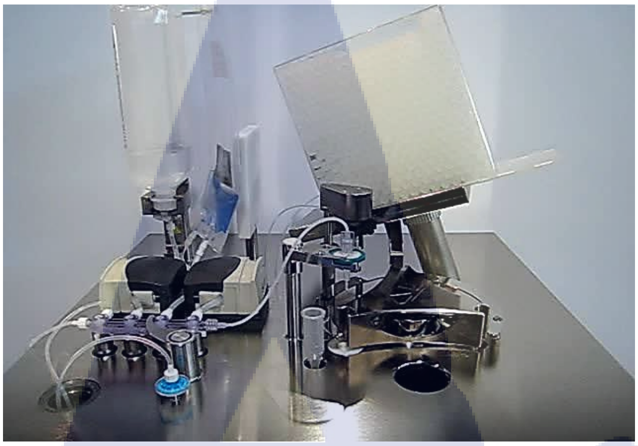

Figure 1.3 Automated Dispenser for Radiopharmaceutical.

1.2 Motivation

As the volume of [^{18}F]-FDG is very little before diluting through saline solution, the accuracy for [^{18}F]-FDG dispenser in [5] dose is only based on operator's skills and the operators have to use hands to check the volume of [^{18}F]-FDG several times using a dose calibrator, which ultimately increase chances to expose receive the radioactive. Therefore, this research aims to decrease the chances for nuclear medicine operators to expose radiation by using video processing technique. It should be noted that only one-time operation is sufficient. It would achieve a high-cost commercial radiopharmaceutical dispenser as a one-time operation, so that the operator's radiation exposure can also be reduced.

1.3 Objectives

1.3.1 To design and implement the cost-effective radiopharmaceutical dispenser using real-time video processing.

1.3.2 To enhance better visualization of [^{18}F]-FDG volume, achieving a precision for only one-time operation to reducing operator's radiation exposure.

1.4 Research Scope

The development of semi-automated radiopharmaceutical dispenser using real-time video processing, the proposed system employs the video camera sends the real-time video signals of the [^{18}F]-FDG volume in a 5-ml syringe to a computer and the volume detection is subsequently performed through video processing using MATLAB. The values of detected volumes are fedback to a micro air pump using a controller Arduino Uno R3 and L293D dc motor controller in order to control the [^{18}F]-FDG volume in the 5-ml syringe automatically. The proposed system offers a potential alternative to high-cost commercial radiopharmaceutical dispenser as a one-time operation can be achieved and operator's radiation exposure can also be reduced.

1.5 Expected Outcome

1.5.1 Achieve the cost-effective radiopharmaceutical dispenser using real-time video processing.

1.5.2 Gain knowledge on the image processing for the real-time video processing.

1.5.3 be able to apply this research to design and implement the cost-effective real-time detections with video camera.

1.6 Definitions

1.6.1 Radiopharmaceutical: any medicinal product which, when ready for use, contains one or more radionuclides (radioactive isotopes) included for a medicinal purpose.

1.6.2 Radiation is the emission and propagation of energy in the form of waves or particles. Radiation waves vary in frequency and wavelength and may be described according to their position on the electromagnetic spectrum. The electromagnetic spectrum includes X- and gamma rays, ultraviolet radiation, visible light, infrared radiation, and radio waves.

1.6.3 Dose: the term dose routinely is used to mean the amount of energy or radiation absorbed in matter. While true in a general sense, this definition must be more carefully qualified to proper certain conditions of irradiation.

1.6.4 Radioactivity: The phenomenon of emission of radiation owing to the spontaneous transformation or disintegration of the radionuclide is known as Radioactivity. However, the term radioactivity is also used to express the physical quantity (activity or strength) of this phenomenon. The radioactivity of a preparation is the number of nuclear disintegrations or transformations per unit time.

1.6.5 Total radioactivity: The radioactivity of the radionuclide per unit of the dispensed formulation (vial, capsule, ampoule, generator, etc) is the total radioactivity, which is an important parameter in dispensing and administration of the radioactive material to the patient as well as from the regulatory requirement for safe handling of the radioactive materials in a facility.

1.6.6 MATLAB (MATrix LABoratory) is a data analysis, prototyping, and visualization tool with built-in support for matrices and matrix operations, excellent graphics capabilities, and a high-level programming language and development environment.

Chapter 2

Related Theories and Literature Reviews

2.1 Introduction

This chapter presents the related theories and literature reviews of the development of semi-automated radiopharmaceutical dispenser using real-time video processing. The two purposes of this chapter are to (1) describe the related theories of this research and (2) describe the literature reviews of this research.

2.2 Related Theories

2.2.1 Radiopharmaceuticals

Radiopharmaceuticals are pharmaceutical formulations consisting of radioactive substances (radioisotopes and molecules labeled with radioisotopes), which are intended for use either in diagnosis or therapy or diagnosis. In imaging, the unique properties of γ-rays emitted from the radioactive isotopes allow the radiopharmaceutical to be traced or their distribution in target tissue imaged non-invasively, thus providing functional information of the target tissue or organ. In therapy, the β-ray energy from the radioisotope is delivered to the target tissue partially or completely to destroy the diseased tissue.

In a pathophysiological state, these targets and processes may be changed significantly compared to their normal state and functionality. Therefore, interaction of the vehicle molecules may also be changed considerably. For example, in many tumours the expression rate of receptors, transporters, enzymes and antigens is modified and these alterations may serve as a suitable predictor for stage and allocation of these tumours. To achieve a personalized diagnosis from outside the body without invasive intervention, suitable interactions between vehicle and target site alone are not enough. It needs for an additional signaller stably attached to the vehicle. Thus, traceability of the pharmaceutical's fate and pathway is guaranteed.

[^{18}F]-FDG is the most widely used PET tracer worldwide. This is due to its versatility most pathological conditions are paired with alterations in glucose management. Hence, applications in therapy monitoring, tumour staging, myocardial energy turnover and many different neurological diseases are found in clinical routine.

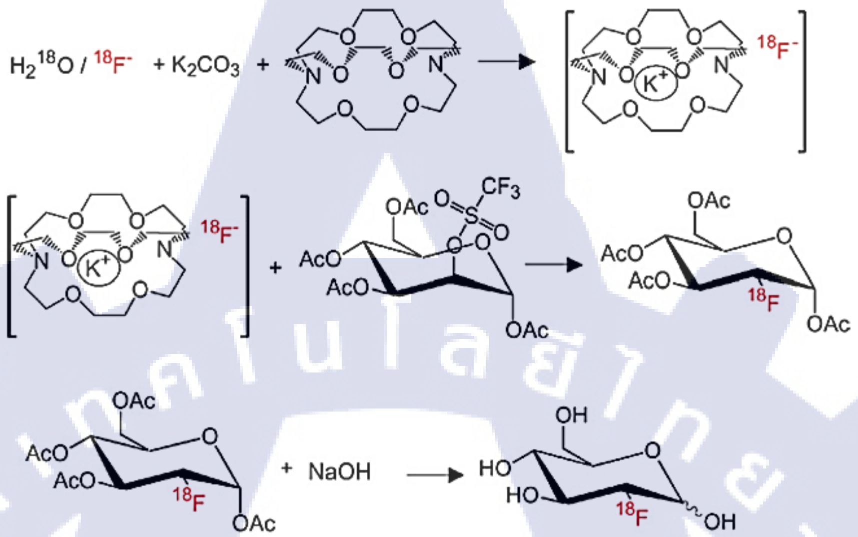

Figure 2.1 Radiosynthesis of [^{18}F]-FDG.

2.2.2 Positron Emission Tomography/Computed Tomography (PET/CT) using [^{18}F]-FDG

PET/CT scans using [^{18}F]-FDG is a nuclear medicine imaging technique evaluating glucose related metabolic processes that the functional information obtained from [^{18}F]-FDG PET has been established to have a significant impact on patient management in oncology. PET/CT scans using [^{18}F]-FDG is used to provide accurate pre-treatment staging, aid in planning of therapy, monitoring response to therapy, restaging and providing assessment of relapse after healing therapy and in radiotherapy treatment planning.

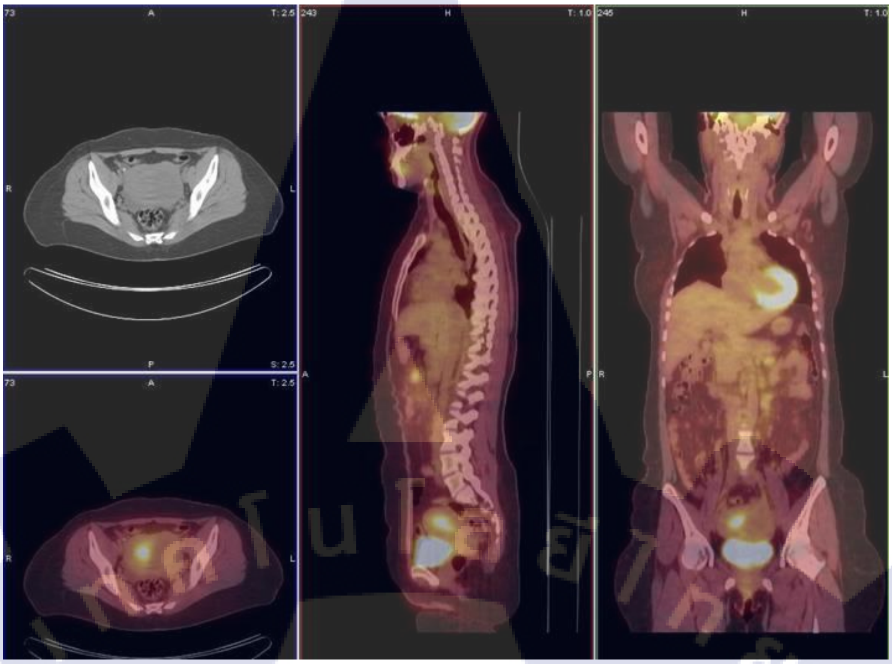

Figure 2.2 PET/CT Images.

The PET tracer shows a central role because it provides the basis both for image quality and clinical interpretation. The radionuclide with its specific physical properties is the working basis for signal detection, transduction and computational translation. On the other hand, understanding the bio-chemical properties of the molecular vehicle such as binding characteristics, metabolism and elimination rate is essential for molecular modelling and dosimetry. From a clinical point of view, basic understanding of radiochemical preparation such as formation of potential by-products, interference of labelled, unlabelled contaminants with the target site and specific radioactivity is necessary for diagnosis using PET/CT.

Figure 2.3 PET/CT Scanner.

2.2.3 Dispensing of [^{18}F]-FDG

The majority of nuclear medicine isotopes are administered to a patient in liquid form. When a radiopharmacy prepares nuclear medicine isotopes, pharmaceutical activity is provided in a concentration of liquid. The concentration is the activity, (typically in mCi) per volume (typically in ml), holds essential information for identifying the exact amount of nuclear isotope in a volume. When a clinic receives a vial containing 100 mCi of an isotope but only needs to inject a patient with 10 mCi, concentration information become essential to knowing how much volume to draw out of the vial for proper patient dosing. In this example, 10 mCi represents 1/10 of a 100 mCi vial, so the radiopharmacist would need to draw 1/10 of the liquid from that vial. But how much volume needs to be drawn. The dispensing needs some more information to make this calculation.

The radiopharmacy should provide the dispensing with concentration, amount of activity and volume in the vial. While all that information is useful, if the radiopharmacy provide the dispensing whit any two of those variable, the third one is simple to figure out. The basic formula to use is:

$$\text{Activity} = \text{Concentration} \times \text{Volume} \tag{2.1}$$

that can be solved for any one of the three variables.

There are many important calculations to make in a clinic when a dose needs to be adjusted to give a patient a specified activity. Although many nuclear medicine clinics today receive unit doses, radiopharmacists still need to have the skill adjusting the patient dose. In a day-to-day operation of a nuclear medicine clinic, a variety of factors require dose adjustment including but not limited to patient coming to their appointment early/late, weight, pediatric, or charge in prescription.

Along with drawing a certain volume for a specific activity amount, radiopharmacists are also asked to dilute doses. Diluting a dose is done to increase the volume of a dose, decrease concentration, or both. Dilution requires an addition of a liquid, usually saline, which always increases volume and decreases concentration (inverse relationship). To calculate the necessary volume needed for proper dilution, use the following formula:

$$\text{Volume (to add to vial)} = \text{Volume (final)} - \text{Volume (initial)} \qquad (2.2)$$

Usually it is necessary to combine radioactivity decay calculation with concentration-volume calculation of the radiopharmaceuticals. Initially the radioactivity decays of each radiopharmaceutical need to be calculated to know the radioactivity remaining in the vial at the injection time. Radioactivity decays at an exponential rate with a decay constant characteristic of each radionuclide. The curve of exponential decay (decay curve) is described by the equation:

$$A_t = A_0 \times e^{-\lambda t} \qquad (2.3)$$

where A_t is the radioactivity at time t, A_0 is the radioactivity at time t = 0, λ is the decay constant characteristic of each radionuclide and e is the base of Napierian logarithms. The half-life ($T_{1/2}$) is related to the decay constant (λ) by the equation:

$$T_{1/2} = \frac{\ln 2}{\lambda} \qquad (2.4)$$

where the half-life ($T_{1/2}$) of [^{18}F]-FDG is 109.77 minutes. The radionuclide is generally identified by its half-life or by the nature and energy of its radiation or radiations or by both, as prescribed in the monograph.

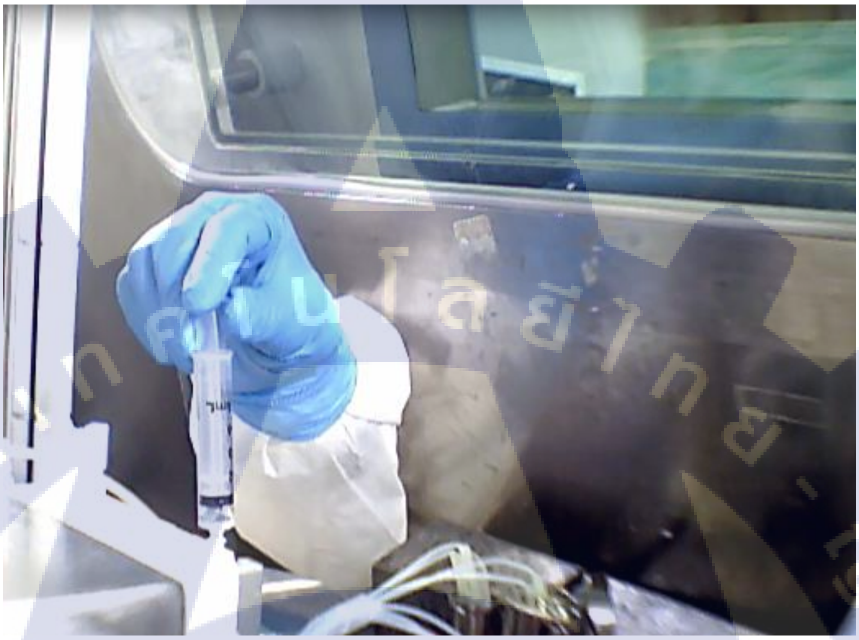

Figure 2.4 Dispensing of [^{18}F]-FDG from the vial.

2.2.3 Radiation Protection

Radiation source such as unsealed radionuclides, sealed sources, X-ray machines, irradiators and other sources can present a hazard of external exposure. Protection from these sources is based on applying three fundamental techniques. The three basic methods used to reduce the external radiation hazard are reducing the time spent near sources (a linear reduction), increasing the distance from sources (an inverse square reduction) and using the shielding of appropriate type (an exponential reduction). Good radiation protection practices require optimization of these fundamental techniques.

2.2.3.1 Time

The amount of radiation an individual accumulates will depend on how long the individual stays in the radiation field. Minimize the time spent near sources will minimize the dose.

$$\text{Dose (mSv)} = \text{Dose Rate (mSv/hr)} \times \text{Time (hr)} \tag{2.5}$$

Therefore, to limit a person's dose, one can restrict the time spent in the area. How long a person can stay in an area without exceeding a prescribed limit is called the stay time, and is calculated from the simple relationship:

$$\text{Stay Time} = \text{Limit (mSv)} / \text{Dose Rate (mSv/hr)} \tag{2.6}$$

2.2.3.2 Distance

Radiation exposure decreases with distance according to the inverse square law. Point sources of x-ray and gamma radiation follow the inverse square law, which states that the intensity of the radiation (I) decreases in proportion to the inverse of the distance from the source (d) squared as follows:

$$I_1 {d_1}^2 = I_2 {d_2}^2 \tag{2.7}$$

Therefore, by knowing the intensity at one distance, one can find the intensity at any other distance.

2.2.3.3 Shielding

Proper shielding can result in an exponential reduction of dose for gamma emitters and a near-total reduction for beta emitters. Select suitable shielding materials during the planning stages of experiment or clinical procedure. The proper material to use depends on the type of radiation and its energy. Alpha and beta radiation, alpha particles are easily shielded. A thin piece of paper or numerous distance of air is usually sufficient to stop them. Therefore, alpha particles present no external radiation hazard. Beta particles are more penetrating than alpha particles.

Beta shields are usually made of aluminum, brass, plastic, or other materials of low atomic number to reduce the production of bremsstrahlung radiation. Lead actually may increase the exposure from certain radionuclides. The yield of bremsstrahlung radiation is proportional to the energy of the beta particles and to the atomic number of the shielding material. Lead has a high atomic number, so the amount of beta-particle energy converted to penetrating bremsstrahlung photons may be large. Although only a small fraction of the beta particles may be converted in this fashion, the resulting photons are more penetrating than the beta particles, resulting in unnecessary dose. Plastics make better shields for beta particles because they have low atomic numbers and little beta energy is converted into photons. In case of very large or energetic beta sources shielding may be layered, with the plastic shield nearest the source and a higher-density shield farthest from the source. The higher-density shield absorbs photons produced by beta interaction in the plastic shield. Lead is a common shielding material for x-rays and gamma radiation because it has a high density, is inexpensive and is relatively easy to work with.

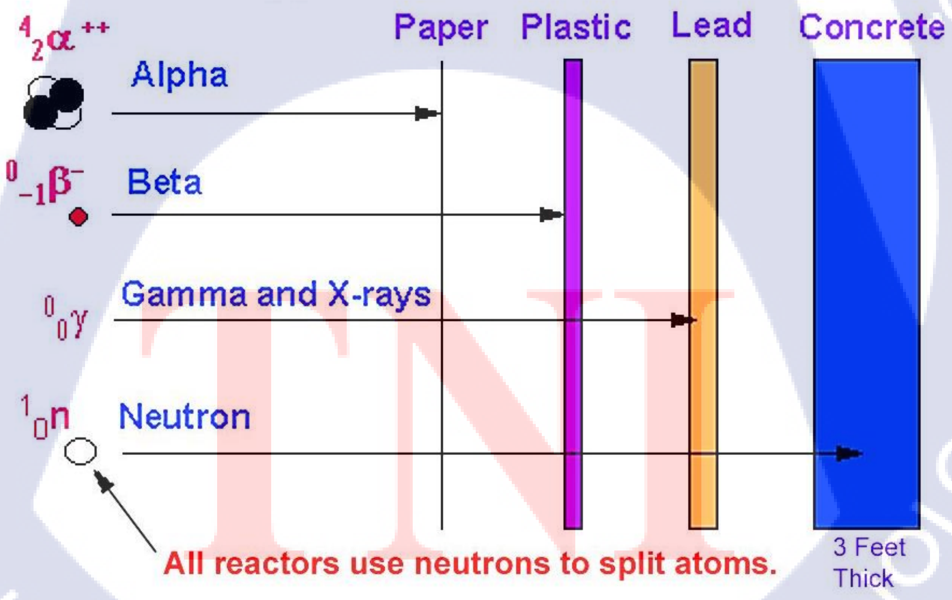

Figure 2.5 Penetrating powers of different kinds of radiation.

2.2.3.4 External Exposure Personnel Monitoring

External radiation exposure is measured by personnel monitoring devices. Personnel monitoring is required when it is likely that an individual will receive in 1 year a dose in excess of 10% of the following table 2.1. Personnel monitoring provides a permanent, legal record of an individual's occupational exposure to radiation. If the body is exposed fairly uniformly, the dosimeter should be worn on the trunk of the body. This will allow the dose to critical organs such as gonads and red bone marrow to be accurately estimated by the dosimeter. When wearing a protective lead apron, the optically stimulated luminescence (OSL) should be worn on the collar, outside of the apron. Ring badges or wrist badges should be worn when large amounts of radioactive materials are handled since the dose to the hands may be high. Ring badges should be worn on the inside of protective gloves to avoid contamination.

Table 2.1 ICPR 60 recommended dose limits.

Category	**Effective dose (in a year)**	**Equivalent dose (in a year)**		
		Lens of the eye	**Extremities**	**Skin**
Occupational Exposure	20 mSv averaged over five consecutive years 50 mSv in any single year	150 mSv	500 mSv	500 mSv
Public Exposure	1 mSv averaged over five consecutive years 5 mSv in any single year	15 mSv	50 mSv	N\A

Figure 2.6 Pocket dosimeter.

Figure 2.7 Optically stimulated luminescence.

Figure 2.8 Ring badges.

2.2.4 Computer Vision and Video Processing

Computer vision and video processing is a particular case of signal processing, which often employs video filters and where the input and output signals are video files or video streams. Video processing is any form of signal processing for which the input is an image, such as photographs or frames of video, the output of image processing can be either an image or a set of characteristics or parameters related to the image. Most image-processing techniques involve treating the image as a two-dimensional signal and applying standard signal-processing techniques. Computer vision is a field that includes methods for acquiring, processing, analyzing, and understanding images and, in general, high-dimensional data from the real world in order to produce numerical or symbolic information, e.g., in the forms of decisions. The development of this field has been to duplicate the abilities of human vision by electronically perceiving and understanding an image. This image understanding can be seen as the disentangling of symbolic information from image data using models constructed with the aid of geometry, physics, statistics, and learning theory. Computer vision has also been described as the enterprise of automating and integrating a wide range of processes and representations for vision perception.

As a scientific discipline, computer vision is concerned with the theory behind artificial systems that extract information from images. The image data can take many forms, such as video sequences, views from multiple cameras, or multi-dimensional data from a medical scanner. As a technological discipline, computer vision seeks to apply its theories and models to the construction of computer vision systems. Sub-domains of computer vision include scene reconstruction, event detection, video tracking, object recognition, learning, indexing, motion estimation, and image restoration. Computer vision often relies on more or less complex assumptions about the scene depicted in an image.

Machine vision is the process of applying a range of technologies & methods to provide imaging-based automatic inspection, process control and robot guidance in industrial applications. Machine vision tends to focus on applications, mainly in manufacturing, e.g., vision based autonomous robots and systems for vision based inspection or measurement. This implies that image sensor technologies and control theory often are integrated with the processing of image data to control a robot and that real-time processing is emphasized by means of efficient implementations in hardware and software. It also implies that the external conditions such as lighting can be and are often more controlled in machine vision than they are in general computer vision, which can enable the use of different algorithms.

There are many kinds of computer vision systems, however all of them contain these basic elements: a power source, at least one image acquisition device such as camera, charge-coupled devices, e.g., a processor as well as control and communication cables or some kind of wireless interconnection mechanism. In addition, a practical vision system contains software, as well as a display in order to monitor the system. Vision systems for inner spaces, as most industrial ones, contain an illumination system and may be placed in a controlled environment. Moreover, a completed system includes many accessories like camera supports, cables and connectors.

Figure 2.9 Object tracking.

2.2.4.1 Object tracking

Object tracking is the process of locating a moving object or multiple objects over time using a camera. It has a variety of uses, some of which are: human-computer interaction, security and surveillance, video communication and compression, augmented reality, traffic control, medical imaging and video editing. Detection of moving objects and motion-based tracking are important components of many computer vision applications, including activity recognition, traffic monitoring, and automotive safety. Object tracking can be a time consuming process due to the amount of data that is contained in video. Adding further to the complexity is the possible need to use object recognition techniques for tracking, a challenging problem in its own right. The objective of video tracking is to associate target objects in consecutive video frames. The association can be especially difficult when the objects are moving fast relative to the frame rate. Another situation that increases the complexity of the problem is when the tracked object changes orientation over time. For these situations video tracking systems usually employ a motion model which describes how the image of the target might change for different possible motions of the object.

2.2.4.2 Object recognition

Object recognition tasks are finding and identifying objects in an image or video sequence. Humans recognize a multitude of objects in images with little effort, despite the fact that the image of the objects may vary somewhat in different viewpoints, in many different sizes and scales or even when they are translated or rotated. Objects can even be recognized when they are partially obstructed from view. This task is still a challenge for computer vision systems. Many approaches to the task have been implemented over multiple decades. Recognition algorithms can be divided into two main approaches, geometric, which look at distinguishing features, or photometric, which is a statistical approach that distills an image into values and compares the values with templates to eliminate variances.

Figure 2.10 Barcode recognition.

2.2.4.3 Face detection

Face detection is a computer technology that determines the locations and sizes of human faces in arbitrary digital images. It detects facial features and ignores anything else, such as buildings, trees and bodies. Face detection can be regarded as a specific case of object-class detection. In object-class detection, the task is to find the locations and sizes of all objects in an image that belong to a given class. Face detection can be regarded as a more general case of face localization. In face localization, the task is to find the locations and sizes of a known number of faces. In face detection, one does not have this additional information. Early face-detection algorithms focused on the detection of frontal human faces, whereas newer algorithms attempt to solve the more general and difficult problem of multi-view face detection. That is, the detection of faces that are either rotated along the axis from the face to the observer (in-plane rotation), or rotated along the vertical or left-right axis (out-of-plane rotation), or both.

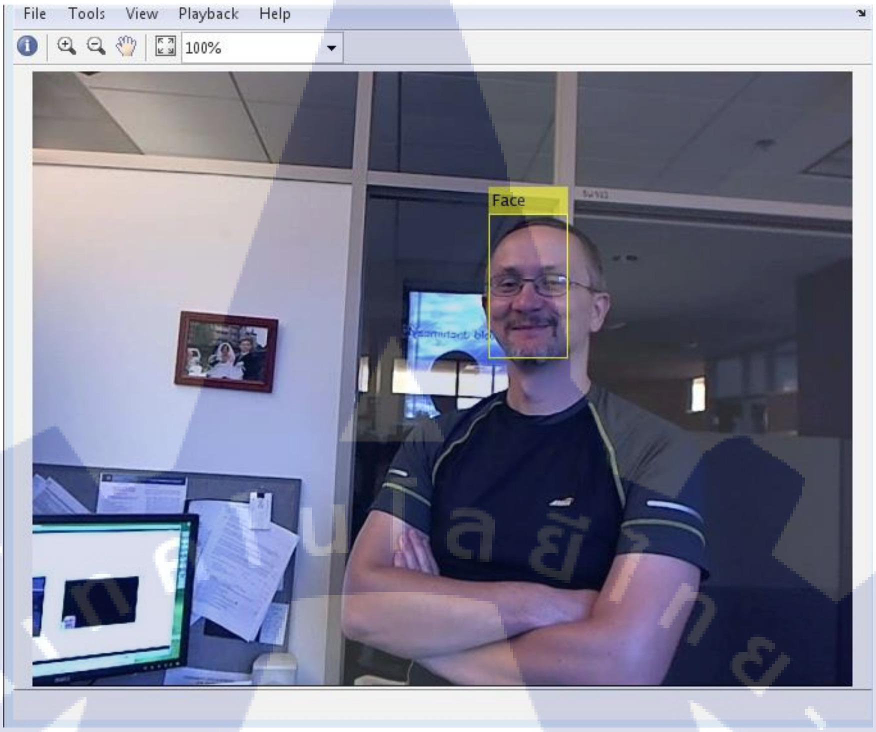

Figure 2.11 Face detection.

The classifier is used to classify the portions of an image, at all locations and scales, as either faces or non-faces (background pattern). Face detection is used in biometrics, often as a part of (or together with) a facial recognition system. It is also used in video surveillance, human computer interface and image database management. Some recent digital cameras use face detection for autofocus. A facial recognition system is a computer application for automatically identifying or verifying a person from a digital image or a video frame from a video source. One of the ways to do this is by comparing selected facial features from the image and a facial database.

2.2.4.4 Motion estimation

Motion estimation is the process of determining motion vectors that describe the transformation from one 2D image to another; usually from adjacent frames in a video sequence. It is an ill-posed problem as the motion is in three dimensions but the images are a projection of the 3D scene onto a 2D plane. The motion vectors may relate to the whole image (global motion estimation) or specific parts, such as rectangular blocks, arbitrary shaped patches or even per pixel. The motion vectors may be represented by a translational model or many other models that can approximate the motion of a real video camera, such as rotation and translation in all three dimensions and zoom. More often than not, the term motion estimation and the term optical flow are used interchangeably.

Figure 2.12 Tracking cars using optical flow results.

2.3 Literature Reviews

Table 2.2 show summarizes research on the radiopharmaceutical dispenser, which is initially reviewed as purpose radiopharmaceutical dispenser. Five mainly linked the development of semi-automated radiopharmaceutical dispenser using real-time video processing have previously been proposed by P. S. Plascjak, et al. [4], C. Tsopelas, P. J. Collins, and C. Blefari [6], J. O Park, et al. [5], S.Thumvijit, and W. Choiprasert [7] and M. Lecchi, et al. [3].

2.3.1 Automated Radiopharmaceutical Dispenser

P. S. Plascjak, et al. [4], purposed an automated radiopharmaceutical dispenser, that offers several advantages over manual procedures, has been developed. It employs a personal computer interfaced to a precision syringe drive module, a dose calibrator, and a printer. The operating program provides menu-selection operation and documentation of procedures and individual doses delivered. All materials in contact with the radiopharmaceutical are sterile and disposable. A novel transport safe is employed to further reduce radiation exposure.

Table 2.2 Research on the radiopharmaceutical dispenser.

Items	Authors	Title
1	P. S. Plascjak, et al. [4]	Automated Radiopharmaceutical Dispenser
2	C. Tsopelas, P. J. Collins, and C. Blefari [6]	A Simple and Effective Technique to Reduce Staff Exposure During the Preparation of Radiopharmaceuticals
3	J. O Park, et al. [5]	Technical note Simple devices for dispensing[^{18}F]FDG
4	S.Thumvijit, and W. Choiprasert [7]	Implementation of automated radiopharmaceutical dispenser with integrated radiation shielding
5	M. Lecchi, et al. [3]	Validation of a new protocol for ^{18}F-FDG infusion using an automatic combined dispenser and injector system

The radiopharmacy in the positron emission tomography department at the National Institutes of Health (NIH) dispenses multiple doses of [^{18}F]-FDG from a single product vial over a 9 hours period. The doses must be precalibrated to deliver the requested amount of [^{18}F]-FDG (usually 185 or 370 MBq [5 or 10 mCi]) at the time of injection. The dose is infused into the patient over several minutes in a volume of 9 mL. The manual dispensing procedure involved withdrawing the individual doses from a vial that initially contained as much as 13 GBq (350 mCi) of [^{18}F]-FDG immediately after being released by quality control. The need to swipe and puncture the vial septum, measure the volume containing the appropriate dose of [^{18}F]-FDG, and dilute to 9 mL, led to potentially high radiation exposure for the radiopharmacist. To reduce this radiation exposure, an automated dispenser was developed. The key design criteria were: a simple setup and operation, accurate dispensing of 185-370 MBq (5-10 mCi) doses of [^{18}F]-FDG in a volume of 9 mL, maintaining purity, sterility and apyrogenicity of the individual doses, and computer control of the process with thorough process and dose documentation.

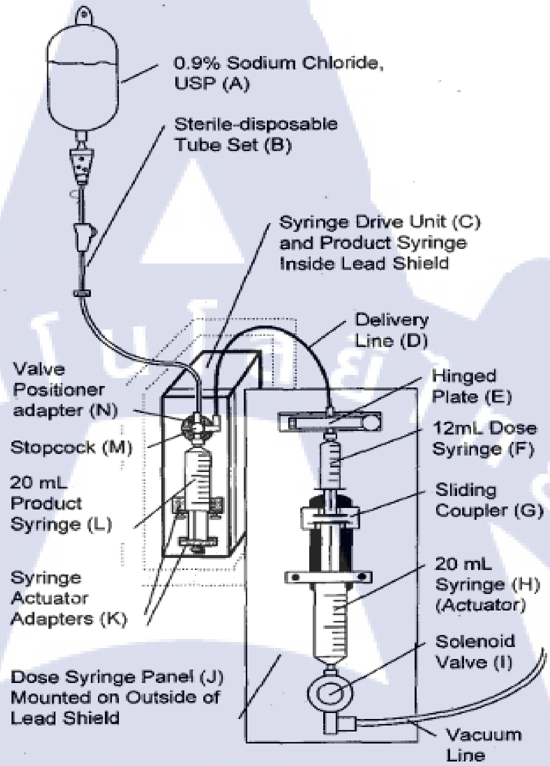

Figure 2.13 Layout of assembled dispensing unit.

2.3.2 A Simple and Effective Technique to Reduce Staff Exposure During the Preparation of Radiopharmaceuticals

C. Tsopelas, P. J. Collins, and C. Blefari [6], In the preparation of radiopharmaceuticals, staffs receive considerable radiation exposure to the hands during withdrawal of activity from the elution vial, from a combination of the syringe and elution vial activities. In an attempt to reduce the radiation burden to the hands, a simple technique was developed that utilizes a modified lead pot lid and a syringe bearing a long needle with a sterile needle guide.

An elution vial in a lead pot with an attached syringe was secured at an angle of 45°, simulating the action of withdrawing ^{99m}Tc-pertechnetate from the elution vial. The ^{99m}Tc activity ratio of vial to syringe was 20:1. A gamma camera detector without collimator was positioned at the syringe plunger and count profiles were obtained after 10 min of data acquisition. The experiment was repeated using the same set-up with the modified lid on the lead pot and a cold syringe to determine the contribution of the radioactive syringe to the count profile. Each experiment was repeated at the vertical position, simulating the normal action of re-dispensing ^{99m}Tc activity into the elution vial.

The modified lid reduced exposure from the elution vial, with a count reduction of 98% for both orientations. The contributions of vial radioactivity to the total count profile were 76% and 84% for vertical and 45° orientations, respectively. The contributions of syringe activity were 24% and 16% for vertical and 45° orientations, respectively.

A reduction in the photon flux to the hands of up to 84% (with an associated reduction in hand dose) can be achieved by withdrawing activity through a modified lid on the lead pot housing the elution vial, without significantly altering normal work practices.

2.3.3 Technical note Simple devices for dispensing [^{18}F]-FDG

J. O Park, et al. [5], High dose [^{18}F]-FDG is prepared routinely using an automated synthesizer. Accordingly, an automated dispenser is needed to dispense [^{18}F]-FDG at the desired dose while reducing the operator’s radiation exposure, and no dispenser capable of vial-to-vial and vial-to-syringe dispensing in one system is commercially available. Here, the authors describe simple devices for the vial-to-vial and vial-to-syringe dispensing of [^{18}F]-FDG. [^{18}F]-FDG is the most commonly used PET radiopharmaceutical, is routinely prepared using an automated synthesizer. Since multiple doses of [^{18}F]-FDG are dispensed from a single production over 8 hours, an automated dispenser is needed to reduce the operator’s radiation exposure. Several automated dispensers are commercially available for [^{18}F]-FDG, which dispense [^{18}F]-FDG from a mother vial to either to vials or syringes. However, no dispenser is currently available that can perform both functions. Thus we investigated the designs of the economical and simple dispensing devices for vial-to-vial and vial-to syringe dispensing of the radiopharmaceuticals.

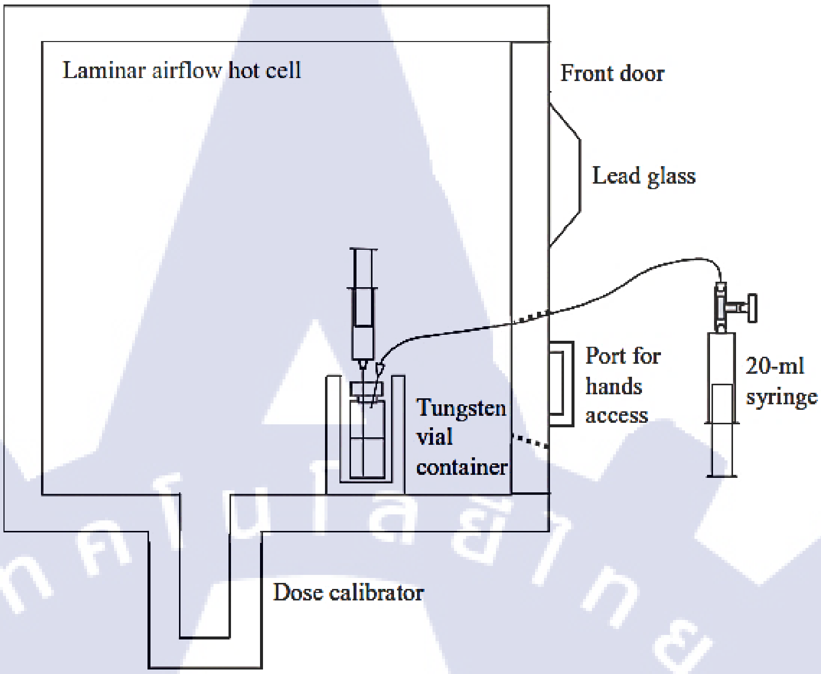

Figure 2.14 A schematic side view of the vial-to-syringe [^{18}F]-FDG dispensing device placed in a laminar airflow hot cell.

<u>2.3.4 Implementation of automated radiopharmaceutical dispenser with integrated radiation shielding</u>

S.Thumvijit, and W. Choiprasert [7], During the preparation of radiopharmaceutical, nuclear medicine staffs receive radiation doses to hands much higher than the other parts of the body. In order to reduce radiation exposure, an automated radiopharmaceutical dispenser was designed and constructed for radiopharmaceutical preparation. The methods of this study included collecting the data, designing and construction of the device. The device comprises of; stand supporting the device, groove part of the device, body part of syringe dispenser with integrated lead for radiation shielding and remotely electrical control part. This device can be used for 3-10 mL syringes with net weigh of 8kg. The complacency of operations of the device was evaluated and the radiation doses were measured by radiation technicians. It was found that this automated radiopharmaceutical dispenser can be used for radiopharmaceutical preparation with the technician’s complacency at good level. The radiation dose rate measured by a survey meter at distance of 10, 30 and 50 cm from the device were 0.30-0.98, 0.02-0.39 and 0.02-0.27 mSv/day respectively, which did not exceed 2 mSv/day effective dose limit of ICRP. It can be concluded that this innovation of an automated radiopharmaceutical dispenser has been successfully constructed.

Figure 2.15 An automated radiopharmaceutical dispenser with integrated radiation shielding.

2.3.5 Validation of a new protocol for ^{18}F-FDG infusion using an automatic combined dispenser and injector system

M. Lecchi, et al. [3], Purpose In nuclear medicine, radiopharmaceuticals are usually administered in unit doses partitioned from multi-dose vials. The partitioning typically takes place in a radiopharmacy, depending on local practice. Automatic, as opposed to manual, partitioning and administration should reduce radiation exposure of the personnel involved, improve the accuracy of the administration and mitigate contamination. This study set out to verify and validate the [^{18}F]-FDG administration procedure performed using Intego™ (MEDRAD, Inc., Warrendale, PA, USA), a combined dispenser and injector system. The authors considered maintenance of sterility and the system's potential to improve, with respect to the manual procedure, the accuracy of net administered [^{18}F]-FDG radioactivity in patients and the radiation protection of operators. Methods a media-fill procedure was used to assess whether sterility is maintained during use of the Intego™ system. Simulating a typical working day's setup and use of the system, the authors investigated the accuracy of the net administered [^{18}F]-FDG activity obtained with Intego™ versus the manual dose delivery system. Authors also measured personnel radiation exposure during use of Intego™ and during manual administration and recorded and compared environmental doses in the two conditions.

Figure 2.16 The Intego™ system.

The radiopharmaceutical remained sterile in all the tests performed. The accuracy of the net [^{18}F]-FDG activity delivered to the patients was found to be within 3 % points, as required by European Association of Nuclear Medicine (EANM) guidelines on [^{18}F]-FDG imaging procedures. With Intego™, the residual radioactivity in the tubing was 0.20 MBq, corresponding to approximately 0.07 %of the mean activity delivered. With manual injection, the residual radioactivity in the syringe averaged 7.37 MBq, corresponding to a mean error of 2.9 % in the delivered dose. During the injection step of the positron emission tomography procedure, whole-body and extremity radiation exposures were significantly reduced with Intego™ by 38 and by 94 %, respectively, compared to the levels associated with manual administration ($p<0.05$).

Intego™ accurately partitions and administers sterile doses of [^{18}F]-FDG from multi-dose vials. Compared with standard manual [^{18}F]-FDG administration, the new procedure with an automatic dispensing and injection system greatly reduces the extremity dose to the operator involved in the administration of the radiopharmaceutical.

2.4 Conclusion

The purpose of this chapter was to describe the related theories of this research of and describe the literature reviews of this research are to the automated radiopharmaceutical dispenser, a simple and effective technique to reduce staff exposure during the preparation of radiopharmaceuticals, technical note simple devices for dispensing[^{18}F]FDG, implementation of automated radiopharmaceutical dispenser with integrated radiation shielding and validation of a new protocol for ^{18}F-FDG infusion using an automatic combined dispenser and injector system.

Chapter 3
Research Methodology

3.1 Introduction

This chapter presents the research methodology for development of semi-automated radiopharmaceutical dispenser using real-time video processing. The five purposes of this chapter are to (1) describe the overall research processes of this research, (2) explain the data collecting and summarization, (3) describe the research tools used in designing the instrument and collecting the data, (4) describe the data analysis methods and (5) describe the research procedures.

3.2 Overall Research Processes

3.2.1 Reviewing relate research paper that focus on radiopharmaceutical dispenser to reducing operator's radiation exposure.

3.2.2 Study the digital image and video processing using MATLAB.

3.2.3 Design the cost-effective radiopharmaceutical dispenser using real-time video processing.

3.2.4 Provide tools and equipment for implement the cost-effective radiopharmaceutical dispenser using real-time video processing.

3.2.5 Implement the cost-effective radiopharmaceutical dispenser using real-time video processing.

3.3 Data Collecting and Summarization

The data collecting in this research study were done by measuring and recording the volume of sterile water in a 5-ml syringe. The result of each dispensing was measured by the analytical balance to record the values into the table.

3.4 Research Tools

3.4.1 In this research, the entire of the programming were perform through MATLAB® version R2014a.

3.4.2 The analytical balance is used to measure the actual volume of sterile water in a 5-ml syringe.

3.5 Data Analysis Methods

3.5.1 The accuracy of volume in a 5-ml syringe that is visible for the operator at different level of dispensing, the volume of sterile water with a step of 0.2 ml. between 0.2 ml. to 2 ml. compared with the actual volume to make the analysis is accurate for only one-time dispensing.

3.5.2 The resulting of the dispensing compared with the actual volume to adjust and control the maximum error of the dispensing and to find the factor for proper instrumentations.

3.6 Research Procedures

3.6.1 Study and analyze the computer vision functions using video camera in MATLAB.

3.6.2 Design and implement the algorithms of volume measurement to measure the volume of sterile water with a step of 0.2 ml. in a 5-ml syringe.

3.6.3 Use the result from 3.5.2 to design and implement the volume controller of semi-automated radiopharmaceutical dispenser using real-time video processing.

3.6.4 Implement and demonstrate the semi-automated radiopharmaceutical dispenser using real-time video processing.

3.6.5 Optimize the system parameters in 3.6.3 and demonstrate the semi-automated radiopharmaceutical dispenser using real-time video processing for data collecting and summarization.

3.7 Conclusion

The purpose of this chapter was to describe the overall research processes of this research, explain the data collecting and summarization, describe the research tools used in designing the instrument and collecting the data, provide an explanation of the statistical procedures used to analyze the data and describe the research procedures.

Chapter 4
Experimental Results

4.1 Introduction

This chapter presents the experimental and experimental results of the development of semi-automated radiopharmaceutical dispenser using real-time video processing.

4.2 Experimental

4.2.1 Experimental Apparatus

Figure 4.1 shows the diagram of the proposed semi-automated radiopharmaceutical dispenser using real-time video processing. The diagram depicts the vial-to-syringe [^{18}F]-FDG dispensing device placed in a manipulation cell. The [^{18}F]-FDG dispensing device is composed of a [^{18}F]-FDG vial, a long needle (18G, 90 mm.), a short needle (20G, 38 mm.), the 5-ml syringe, an extension tube (0.9 mm i.d., 1000 mm length), the three-way stopcock, the video camera (Web camera, 2MP), the computer with MATLAB, the micro air pump (OKEN SEIKO, P36B-0002R), Arduino Uno R3, L293D dc motor controller and the sterile air filter (0.20 µm, Millipore Corp.) [5]. The 5-ml syringe with a long needle is put into the [^{18}F]-FDG vial in a tungsten vial container. One of the ports is marginally open to allow accessing to the extension tube.

The micro air pump, Arduino Uno R3 and L293D dc motor controller are located outside the manipulation cell and connected to the [^{18}F]-FDG vial through the three-way stopcock, the extension tube and the sterile air filter connected to the short needle. The required volume for an individual dose is calculated from the total radioactivity and the volume of [^{18}F]-FDG (Concentration) in the [^{18}F]-FDG vial. The required volume of [^{18}F]-FDG has been dispensed from the [^{18}F]-FDG vial so that after the 5-ml syringe is filled with normal saline, the total injection volume in the syringe will be 3 to 4 ml. The filled 5-ml syringe is attached to a long needle that has been inserted into the bottom of the [^{18}F]-FDG vial. The three-way stopcock is then positioned toward the micro air pump and the [^{18}F]-FDG vial. Air is slowly pushed through the extension tube and the sterile air filter from the micro air pump, and then push the [^{18}F]-FDG in the vial. The [^{18}F]-FDG in the vial has been transferred until the 5-ml syringe plunger is moved upward to reach the required volume.

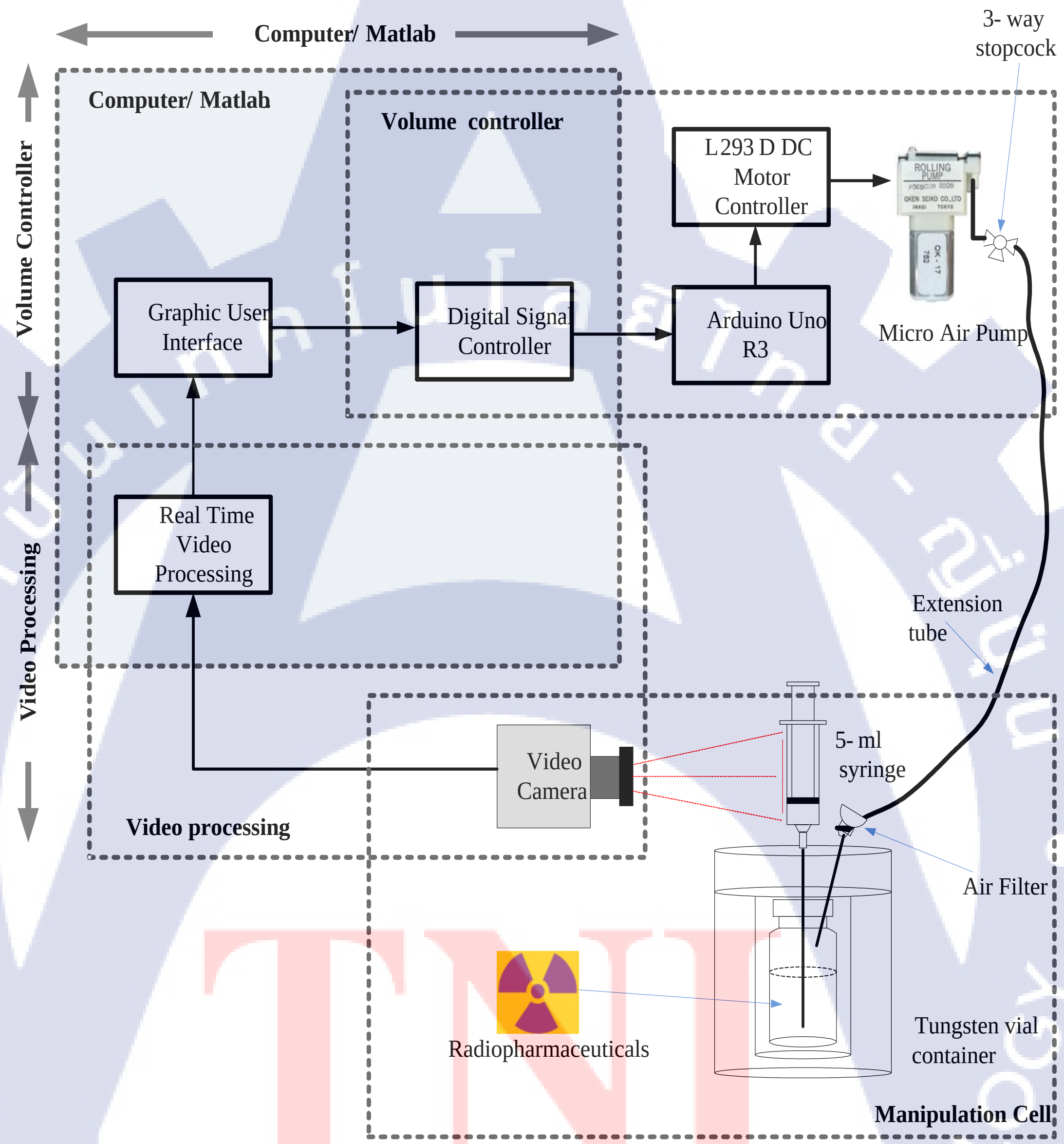

Figure 4.1 The diagram of the proposed semi-automated radiopharmaceutical dispenser using real-time video processing.

The real-time video processing of the 5-ml syringe plunger showing an automated calculation volume of [^{18}F]-FDG with the 5-ml syringe plunger is moved upward to reach the required volume during the [^{18}F]-FDG dispensing from the [^{18}F]-FDG to the 5-ml syringe on the computer screen. The values of detected volumes are fedback to the micro air pump using the L293D dc motor controller and the Arduino Uno R3 in order to control the volume of [^{18}F]-FDG in the 5-ml syringe automatically. After dispensing the three-way stopcock handle is rotated to vent air pressure in the [^{18}F]-FDG vial, the 5-ml syringe is then manually removed from the [^{18}F]-FDG vial, filled with the normal saline. The total injection volume in the 5-ml syringe will be 3 to 4 ml. and ready for delivery to the patient. The process can be repeated by replacing the new 5-ml syringe.

Figure 4.2 The Photographs of the original beveling view of a manipulation cell that is visible for the operator.

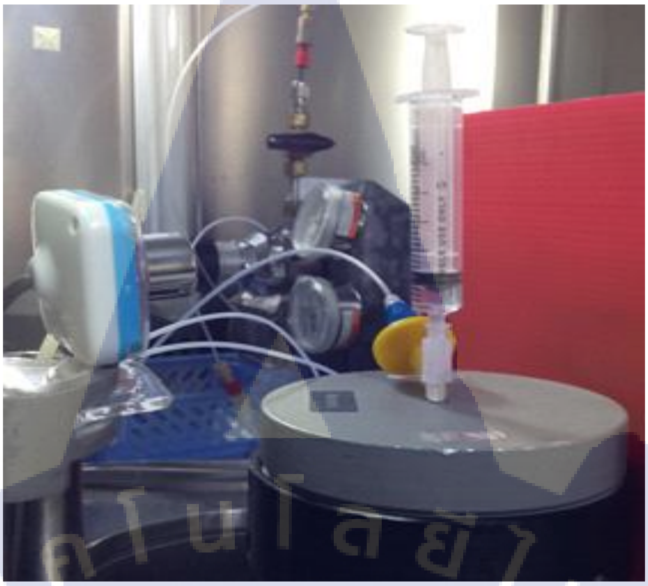

Figure 4.3 The Photographs of the proposed video camera with close distance.

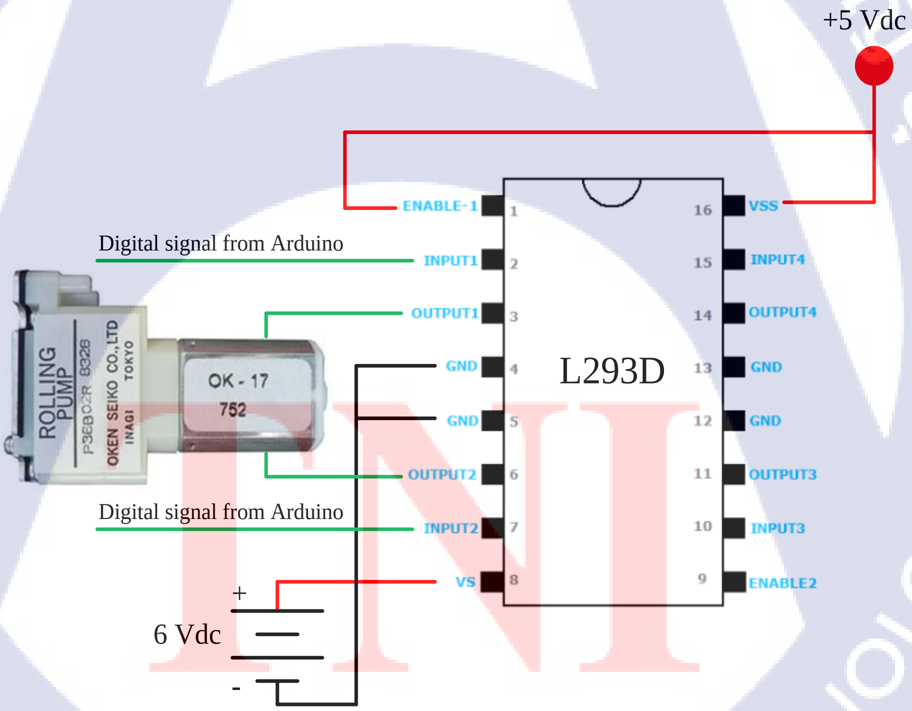

Figure 4.4 Diagram of volume controller for experimental set-up and demonstrations.

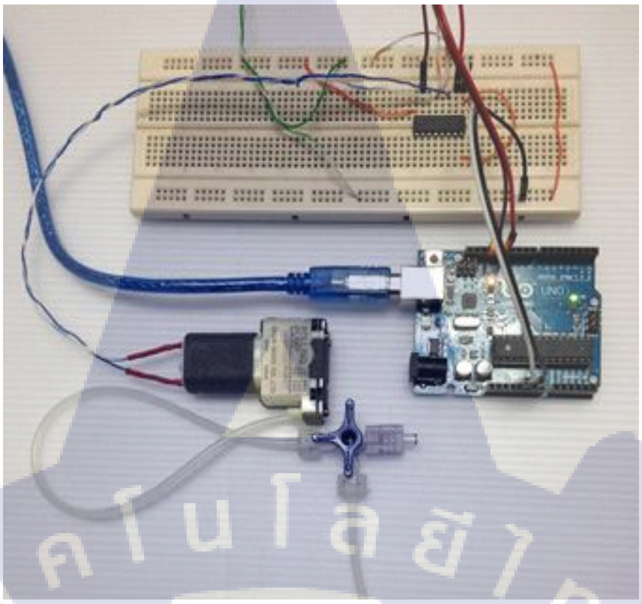

Figure 4.5 The photographs of prototype of the proposed system.

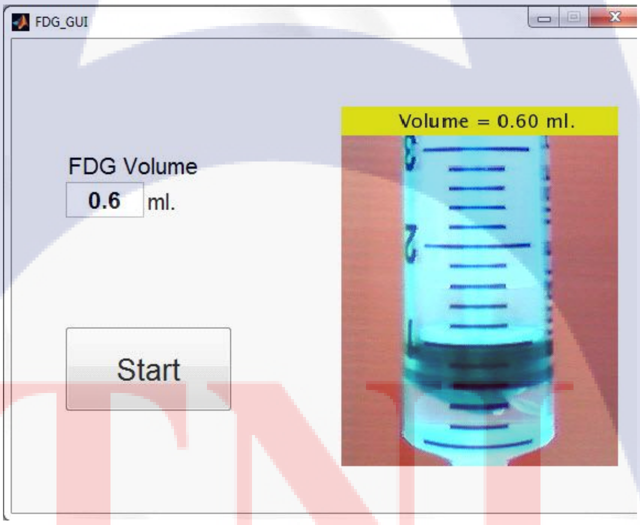

Figure 4.6 The GUI of the proposed system.

4.2.2 Video Processing Technique

Figure 4.7 shows th image results of video processing technique that used for the volume calculation of the development of semi-automated radiopharmaceutical dispenser using real-time video processing. The video processing technique consist as follows

4.2.2.1 Otsu’s method is used for converts RGB color space to intensity the image.

4.2.2.2 Labeling is used for label all the connected components in the image

4.2.2.3 Median filter is used for noise filtering.

4.2.2.4 Iamge histogram is used for selecting the pixel of white-color to count and calculate for detecting the volume.

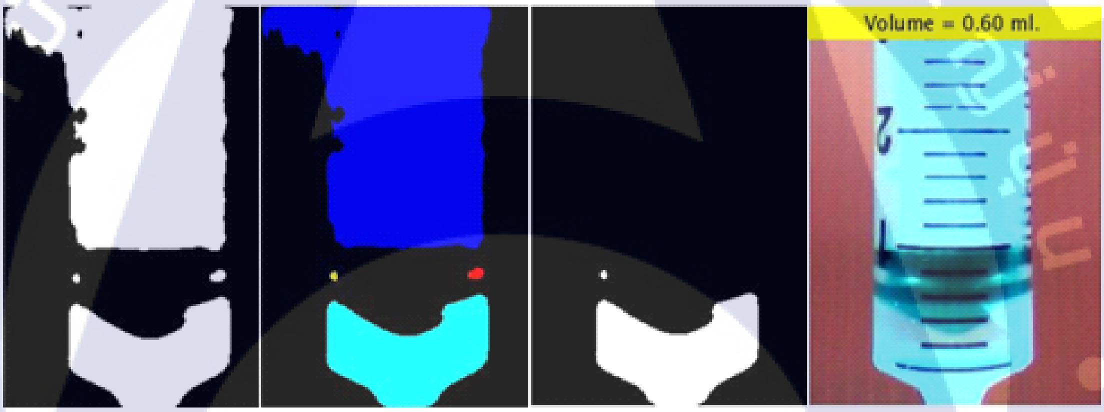

Figure 4.7 The image results of video processing technique.

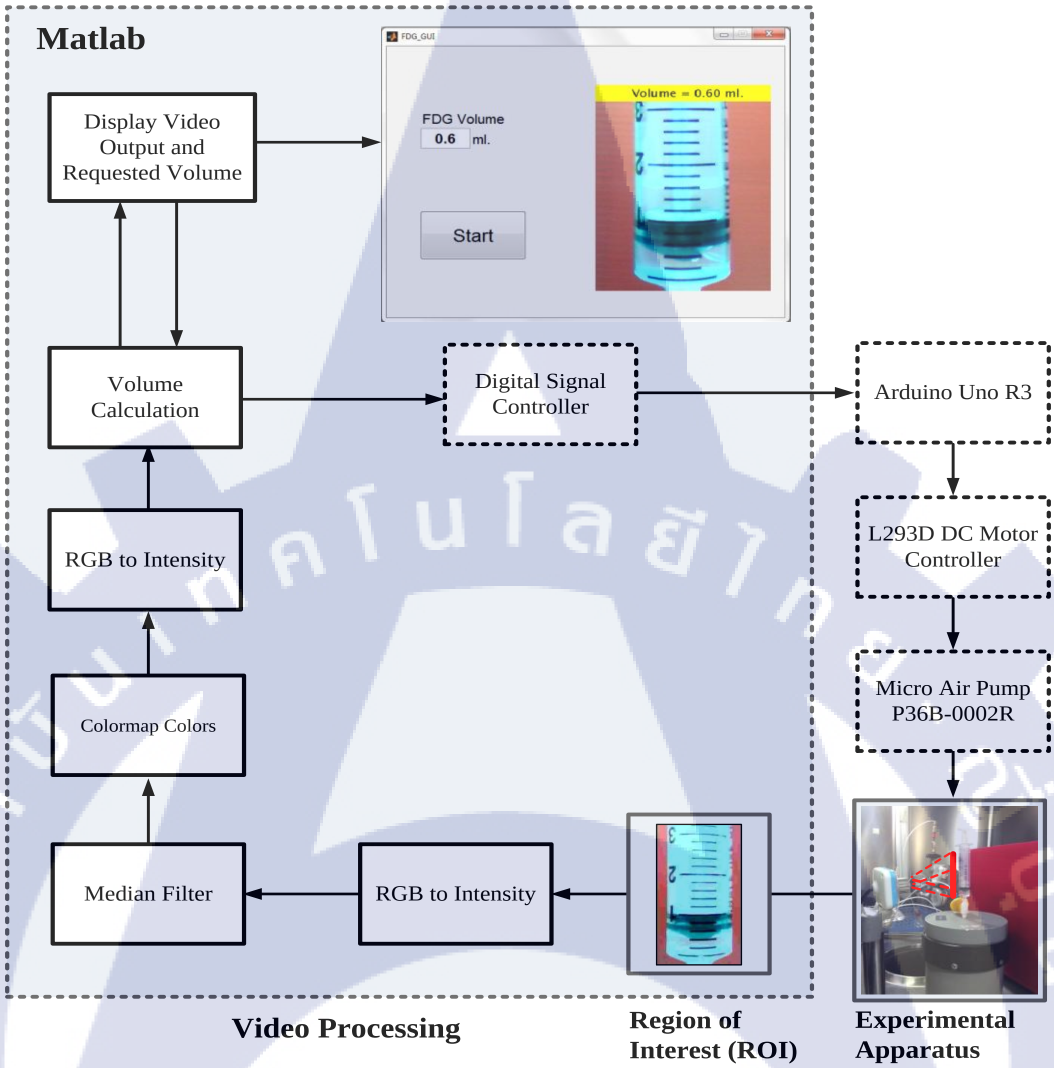

Figure 4.8 Diagram of overall operation procedures through video processing technique.

Figure 4.8 shows the diagram of overall operation procedures through video processing technique, the Region of Interest (ROI), video processing in MATLAB and volume controller. At the beginning, the real-time video processing using the video camera sends a real-time video signals of the [^{18}F]-FDG volume in the 5-ml syringe to the computer at 15 Frames Per Second (FPS). Next the computer is processes the image of the 5-ml syringe using a computer vision system toolbox for image processing. The Region of Interest (ROI) is used in selecting a view of the scale on the 5-ml syringe with red color background. The color space conversion converts RGB color space to intensity the image using Otsu's method, the median filter is used for noise filtering. Next converts label matrix into RGB image and converts RGB color space to intensity the image. Finally, the pixel of white-color is counted and calculated for detecting the volume to send digital signal output are fedback to the Arduino Uno R3 in order to control the micro air pump using the L293D dc motor controller and consequently the computer screen displays the real-time volume of [^{18}F]-FDG in the 5-ml syringe inside the manipulation cell.

The main feature of the proposed video processing techniques is the real-time control and monitoring of [^{18}F]-FDG volume automatically and it is no longer needed to measure by eye approximation. Figure 4.4 shows the diagram of the volume controller for experimental set-up and demonstrations. The digital signal output are fedback to the Arduino Uno R3 in order to control the micro air pump using the L293D dc motor controller.

4.3 Experiment Results

Figure 4.2, 4.3, 4.5 and 4.6 show the photographs of experimental set-up during demonstrations. It can be seen in Figure 4.2 that the original beveling view (approximately 45 Degree) of the manipulation cell that is visible for the operator is relatively difficult to dispense [^{18}F]-FDG. Therefore, the operator must have high skill in approximating the volume of [^{18}F]-FDG in a syringe. Figure 4.3 shows the proposed video camera with close distance of 6 cm. in reading the level of [^{18}F]-FDG in a syringe. Figure 4.5 shows the prototype of the proposed system (the volume controller) where operator can dispense [^{18}F]-FDG outside the manipulation cell. Figure 4.6 shows the GUI of the proposed system.

Figure 4.9 depicts the photographs of a 5-ml syringe that is visible for the operator at different level of dispensing [^{18}F]-FDG; with a step of 0.2 ml.. It can be seen from Fig.6 that the visible syringe is large and no longer bevel. This helps the operator to read the scale easily. As illustrated in Figure 4.9, the entire syringe plunger is located at the exact location on the syringe and the calculated volume can be read easily.

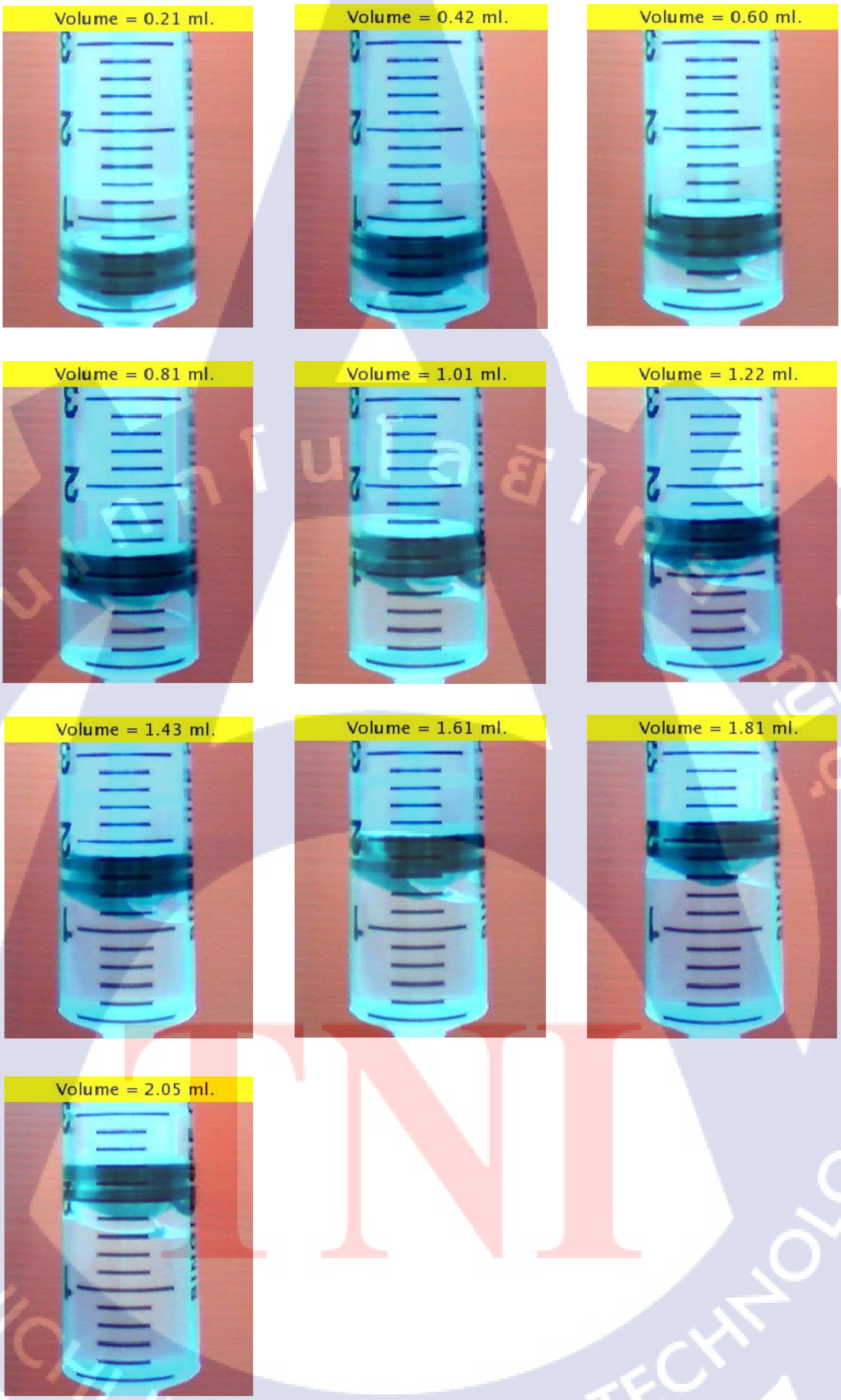

Figure 4.9 The Photographs of a 5-ml syringe that is visible for the operator at different level of dispensing [^{18}F]-FDG with a step of 0.2 ml..

Table 4.1 Comparisons of the actual volume and the measured [^{18}F]-FDG volume using the proposed technique.

Actual Volume (ml.)	Minimum - Maximum of Measured Volume (ml.)	Maximum Percentage of Errors (%)
0.2	0.19 - 0.21	5
0.4	0.38 - 0.42	5
0.6	0.59 - 0.62	3
0.8	0.78 - 0.82	2.5
1	0.98 - 1.03	3
1.2	1.19 - 1.22	1.7
1.4	1.38 - 1.43	2.1
1.6	1.57 - 1.62	1.9
1.8	1.77 - 1.83	1.7
2	1.98 - 2.05	2.5

It can be considered that the radiopharmaceutical dispensing with real-time video processing technique using the video camera can enhance the operator to dispense radiopharmaceutical effectively. The precision of the required volume and the vision would be better manual operation. The operator can simply dispense the [^{18}F]-FDG volume at only one-time operation, especially in case of low required volume, i.e. high concentration. In addition, the operator can control the required volume outside the manipulation cell by GUI with high precision. In terms of accuracy, Table 4.1 summarizes the comparison between the required volume and the measured volume using the proposed video processing technique with an automated volume controller. It can be considered from the table 4.1 that the maximum error is at 5% for 0.2 to 2 ml. which is a percent error or difference of less than 10% will be acceptable, proving more efficient than using manual dispensing whit a direct eye sight. Therefore, the precision of required [^{18}F]-FDG dose is no longer based on operator’s skills. Moreover, this technique can reduced radiation exposures with cost-effective implementation.

4.4 Conclusion

The purpose of this chapter was to describe the experimental results of this research, explain the experimental and describe the experimental results of the development of semi-automated radiopharmaceutical dispenser using real-time video processing. The maximum error is at 5% for 0.2 to 2 ml. which is a percent error or difference of less than 10% will be acceptable, proving more efficient than using manual dispensing whit a direct eye sight.

Chapter 5
Conclusion

5.1 Introduction

This chapter presents the conclusion of the development of semi-automated radiopharmaceutical dispenser using real-time video processing.

5.2 Conclusion

The [^{18}F]-FDG is the most widely used PET tracer worldwide. In the preparation process of the radiopharmaceuticals or PET radionuclides as [^{18}F]-FDG, the large amounts of radioactivity emitting high-energy annihilation photons need to be handled. Therefore, the level of exposure in nuclear medicine workers is anticipated to be high during the production and dispensing of [^{18}F]-FDG and administration of [^{18}F]-FDG chemicals, etc. It is necessary to take radiation protection measures appropriate to the characteristics of PET tracers. As the exposure level depends on the time during which radionuclides are handled and distance from the source, the nuclear medicine worker must be very skilled in the operating procedures. It is necessary to make efforts to shorten the time during which the worker is in contact with the [^{18}F]-FDG. Thus an automated dispenser is needed to reduce the operator's radiation exposure.

Several automated dispensers are commercially available for [^{18}F]-FDG, which dispense [^{18}F]-FDG from vial-to-vial and vial-to syringe. Those automated dispensers are relatively costly and need replacing the consumable parts in a day. However, the dispensing of [^{18}F]-FDG in many hospitals are using manual operation for small amount of patient in a day for economic reasons. Therefore, the research aims to integrate of knowledge on image processing in the computer engineering field to enhance the nuclear medicine in the medical field.

From the research results in chapter 4, that the maximum error is at 5% for 0.2 to 2 ml. which is a percent error or difference of less than 10% will be acceptable, proving more efficient than using manual dispensing whit a direct eye sight. Therefore, the precision of required [^{18}F]-FDG dose is no longer based on operator's skills. Moreover, this technique can reduced radiation exposures with cost-effective implementation. It can be considered from the table 5.1 that the fully automated radiopharmaceutical dispenser is relatively costly whilst a manual dispenser is harmful to operators caused by radiation exposures. Hence, the research could develop a cost-effective radiopharmaceutical dispenser with real-time video processing system. The proposed system employs the video camera sending the real-time video signals of the [^{18}F]-FDG volume in the 5-ml syringe to a computer, enlarging syringe volume display by a video processing based on MATLAB. The volume control was done by air flowing slowly through an extension tube from the micro air pump to the [^{18}F]-FDG vial until the 5-ml syringe plunger is moved to obtain the required volume automatically. The computer dispenses the [^{18}F]-FDG volume and displays an automated calculation volume of [^{18}F]-FDG to help the operator and to enhance better visualization of [^{18}F]-FDG volume. Therefore, only once operation is sufficient for radiopharmaceutical preparation. Finally, the developed approach could offer a solution to high-cost commercial radiopharmaceutical dispenser, obtain a high precision, and reduce operator's radiation exposure.

Table 5.1 The dispensing methods comparison.

Dispensing Methods	**Precision of Dispensing**	**Reducing operator's radiation exposure**	**Cost-effective**
Automated Dispenser	100%	100%	Approximately 5,000,000 ฿
Manual Dispensing	50%	0%	0 ฿
The Semi-Automated Radiopharmaceutical Dispenser using Real-Time Video Processing	100%	50%	Approximately 6,000 ฿

5.3 Conclusion

The purpose of this chapter was to describe the conclusion of this research that the proposed system offers a potential alternative to high-cost commercial radiopharmaceutical dispenser achieving a high precision for only one-time operation and reducing operator's radiation exposure.

Appendix

1. Matlab code for GUI of semi-automated radiopharmaceutical dispenser using real-time video processing program.

```
function varargout = FDG_GUI(varargin)
clear all

    % Begin initialization code
    gui_Singleton = 1;
    gui_State = struct('gui_Name',       mfilename, ...
                'gui_Singleton',  gui_Singleton, ...
                'gui_OpeningFcn', @FDG_GUI_OpeningFcn, ...
                'gui_OutputFcn',  @FDG_GUI_OutputFcn, ...
                'gui_LayoutFcn',  [] , ...
                'gui_Callback',   []);
    if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
    end

    if nargout
        [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
    else
        gui_mainfcn(gui_State, varargin{:});
end

% --- Executes just before FDG_GUI is made visible.
function FDG_GUI_OpeningFcn(hObject, eventdata, handles, varargin)

    % Choose default command line output for FDG_GUI
    handles.output = hObject;

    % vid = videoinput('winvideo', 2);
    handles.vid = videoinput('winvideo',2,'YUY2_640x480');
    handles.vid.ROIPosition = [202 158 231 321];
```

```
        % Set the properties of the video object
        set(handles.vid, 'FramesPerTrigger', Inf);
        set(handles.vid, 'ReturnedColorspace', 'rgb');
        handles.vid.FrameGrabInterval = 5;
        guidata(hObject, handles);

% UIWAIT makes FDG_GUI wait for user response (see UIRESUME)
uiwait(handles.figure1);

% Get default command line output from handles structure
handles.output = hObject;
varargout{1} = handles.output;

function edit1_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function edit1_CreateFcn(hObject, eventdata, handles)

        % hObject    handle to edit1 (see GCBO)
        if ispc
        set(hObject,'BackgroundColor','white');
        else
        set(hObject,'BackgroundColor',get(0,'defaultUicontrolBackgroundColor'));
end

% --- Executes on button press in pushbutton1.
function pushbutton1_Callback(hObject, eventdata, handles)
        % create arduino object and connect to board
        if exist('handles.a','var') && isa(handles.a,'arduino') && isvalid(handles.a),
        else
        handles.a=arduino('COM3');
```

```
end

% basic analog and digital IO
pinMode(handles.a,12,'output');
fdg=get(handles.edit1,'string');
fdg=str2num(fdg);

%start the video aquisition here
start(handles.vid)

% Set a loop that stop after 300 frames of aquisition
while(handles.vid.FramesAcquired<=300)

% Get the snapshot of the current frame
data = getsnapshot(handles.vid);

% Use a median filter to filter out noise
level=graythresh(data);
bb=im2bw(data,level);
bw = medfilt2(bb, [12 12]);

% Label all the connected components in the image.
q=bwlabel(bw,4);
w=label2rgb(q,@jet,'k');

% Convert the resulting grayscale image into a binary image.
level2=graythresh(w);
diff=im2bw(w,level2);

% Count white region
s=imhist(diff);
j=s(2,:)*(10^-4);
```

```
        % Adjustment
        Vol=j*1.02;

        % Label white pixels value in the image.
        frameBlobTxt = sprintf('        Volume = %.2f ml.          ', Vol);
        data = insertText(data, [1 1], frameBlobTxt, ...
        'FontSize', 16, 'BoxOpacity', 1, 'TextColor', 'black');

        if Vol < fdg-0.094;
        digitalWrite(handles.a,12,1);
        else
        digitalWrite(handles.a,12,0);
        end

        % Display the image
         imagesc(data);axis off;

end

% Stop the video aquisition.
stop(handles.vid);
flushdata(handles.vid);
clear all
```

The Development of Semi-Automated Radiopharmaceutical Dispenser using Real-Time Video Processing

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***Abstract*— This paper presents the development of a semi-automated radiopharmaceutical dispenser using real-time video processing. Typically, a fully-automated radiopharmaceutical dispenser is expensive while a manual dispenser is harmful to operators due to radiation exposures. In the proposed system, the video camera sends the real-time video signals of the [^{18}F]-Fluorodeoxyglucose ([^{18}F]-FDG) volume in a 5-ml syringe to a computer and the volume detection is subsequently performed through video processing using MATLAB. Air is slowly pushed through an extension tube from a micro air pump to the [^{18}F]-FDG vial until the 5-ml syringe plunger is moved to reach the [^{18}F]-FDG required volume automatically. The computer subsequently displays an automated calculation volume of [^{18}F]-FDG for the operator that help a better vision of the volume of [^{18}F]-FDG and therefore a one-time operation is sufficient. The proposed system offers a potential alternative to high-cost commercial radiopharmaceutical dispenser achieving a high precision and reducing operator's radiation exposure.**

Keywords*— *Radiopharmaceutical Dispenser Semi-Automation; Real-Time Video Processing; Volume Measurementcomponent

I. INTRODUCTION

Nuclear medicine is a medical specialty that includes applications in radioactive substances in disease diagnosis and treatment processes. The [^{18}F]-Fluorodeoxyglucose, which is also commonly abbreviated [^{18}F]-FDG and generally utilized Positron Emission Tomography/Computed Tomography (PET/CT). Radiopharmaceutical is regularly prepared using an automated synthesizer. Uptaking the [^{18}F]-FDG by human tissues is an indication for the tissue uptake of glucose that is closely correlated with certain types of tissue metabolism [1]. Consequently, the PET/CT scanner can proceed either two-dimensional or three-dimensional images of the distribution of [^{18}F]-FDG throughout the patient body after the injection of [^{18}F]-FDG. The PET/CT images are used to staging, restaging, planning and monitoring therapies in various cancer patients, including uterine cancer. Figure 1 illustrates a 66-year-old female with endometrial cancer with uptake on [^{18}F]-FDG using hybrid PET/CT systems [2]. In the preparation process of the [^{18}F]-FDG, nuclear medicine operators such as pharmacist, nurse, chemist and doctor would certainly receive a radiation burden to the whole body and hands resulting from preparing radiopharmaceutical doses and also administration of patient doses and contact [3]. As multiple doses of [^{18}F]-FDG are dispensed from a single production over eight hours, an automated dispenser is needed to reduce the operator's radiation exposure [4]. Despite the fact that numerous automated dispensers are commercially available for [^{18}F]-FDG that are available in the form of vials or syringes, those automated dispensers are relatively costly.

However, the preparation of [^{18}F]-FDG in practice in many hospitals are using manual operation for small amount of [^{18}F]-FDG dispenser for economic reasons. In the case where manual operations are considered, there has been a report of a simple device for dispensing [^{18}F]-FDG from Jong O Park and et al. [5] that realizes the vial-to-vial and vial-to-syringe technique using an airflow to control the volume of [^{18}F]-FDG in order to decrease chances to receive a radiation exposures to the whole body and hands.

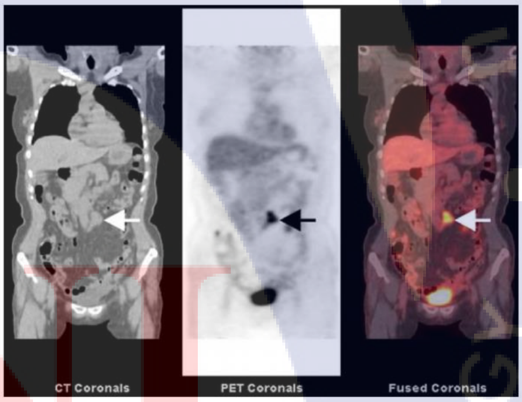

Fig. 1. A 66-year-old female with endometrial cancer and PALN metastases (arrows) on FDG PET/CT images [2].

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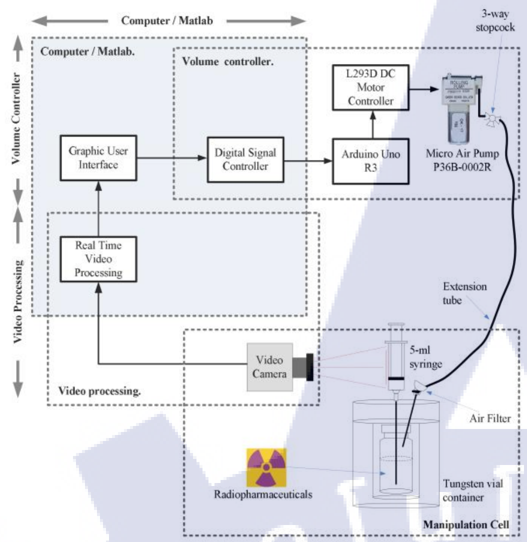

Fig. 2. Diagram of the proposed semi-automated radiopharmaceutical dispenser using real-time video processing.

As the volume of [^{18}F]-FDG is very little before diluting through saline solution, the accuracy for [^{18}F]-FDG dispenser in [5] dose is only based on operator's skills and the operators have to use hands to check the volume of [^{18}F]-FDG several times using a dose calibrator, which ultimately increase chances to expose receive the radioactive.

Therefore, this paper aims to decrease the chances for nuclear medicine operators to expose radiation by using video processing technique. The proposed system employs the video camera that sends a real-time video signals of the [^{18}F]-FDG volume in the 5-ml syringe to a computer and the volume detection is subsequently performed through video processing using MATLAB. Air is slowly pushed through an extension tube from the micro air pump to the [^{18}F]-FDG vial until the 5-ml syringe plunger is moved to reach the required volume. The computer subsequently displays an automated calculation volume of [^{18}F]-FDG to enhance the operator vision of the volume of [^{18}F]-FDG. It should be noted that only one-time operation is sufficient. It would achieve a high-cost commercial radiopharmaceutical dispenser as a high precision, so that the operator's radiation exposure can also be reduced.

II. Proposed Semi-Automated Radiopharmaceutical Dispenser using Real-Time Video Processing

A. Experimental Apparatus

Figure 2 is the diagram of the proposed semi-automated radiopharmaceutical dispenser using real-time video processing. The diagram depicts the vial-to-syringe [^{18}F]-FDG dispensing device placed in a manipulation cell. The [^{18}F]-FDG dispensing device is composed of a [^{18}F]-FDG vial, a long needle (18G, 90 mm.), a short needle (20G, 38 mm.), the 5-ml syringe, an extension tube (0.9 mm i.d., 1000 mm length), the three-way stopcock, the video camera (Web camera, 20MP), the computer with MATLAB, the micro air pump (OKEN SEIKO, P36B-0002R), Arduino Uno R3, L293D dc motor controller and the sterile air filter (0.20 µm, Millipore Corp.) [5]. The 5-ml syringe with a long needle is put into the [^{18}F]-FDG vial in a tungsten vial container. One of the ports is marginally open to allow accessing to the extension tube.

The micro air pump, Arduino Uno R3 and L293D dc motor controller are located outside the manipulation cell and connected to the [^{18}F]-FDG vial through the three-way stopcock, the extension tube and the sterile air filter connected to the short needle. The required volume for an individual dose is calculated from the total radioactivity and the volume of [^{18}F]-FDG (Concentration) in the [^{18}F]-FDG vial. The required volume of [^{18}F]-FDG has been dispensed from the [^{18}F]-FDG vial so that after the 5-ml syringe is filled with normal saline, the total injection volume in the syringe will be 3 to 4 ml. The filled 5-ml syringe is attached to a long needle that has been inserted into the bottom of the [^{18}F]-FDG vial. The three-way stopcock is then positioned toward the micro air pump and the [^{18}F]-FDG vial. Air is slowly pushed through the extension tube and the sterile air filter from the micro air pump, and then push the [^{18}F]-FDG in the vial. The [^{18}F]-FDG in the vial has been transferred until the 5-ml syringe plunger is moved upward to reach the required volume.

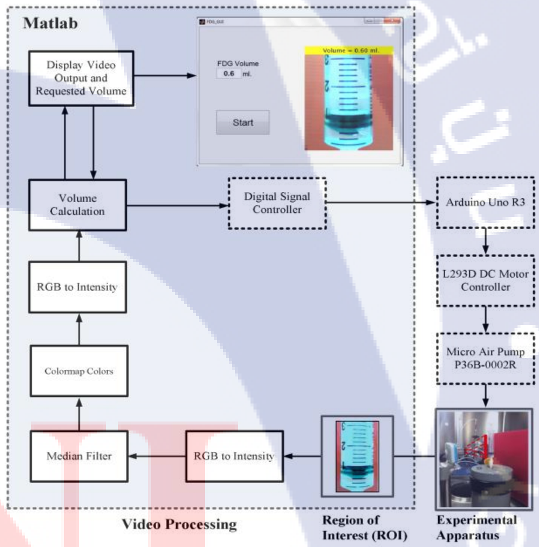

Fig. 3. Diagram of overall operation procedures through video processing technique, showing the region of interest (ROI), video processing in MATLAB and volume controller.

The real-time video processing of the 5-ml syringe plunger showing an automated calculation volume of [^{18}F]-FDG with the 5-ml syringe plunger is moved upward to reach the required volume during the [^{18}F]-FDG dispensing from the [^{18}F]-FDG to the 5-ml syringe on the computer screen. The values of detected volumes are fedback to the micro air pump using the L293D dc motor controller and the Arduino Uno R3 in order to control the volume of [^{18}F]-FDG in the 5-ml syringe automatically. After dispensing the three-way stopcock handle is rotated to vent air pressure in the [^{18}F]-FDG vial, the 5-ml syringe is then manually removed from the [^{18}F]-FDG vial, filled with the normal saline. The total injection volume in the 5-ml syringe will be 3 to 4 ml. and ready for delivery to the patient. The process can be repeated by replacing the new 5-ml syringe.

B. *Video Processing Technique*

Figure 3 shows the diagram of overall operation procedures through video processing technique, the Region of Interest (ROI), video processing in MATLAB and volume controller. At the beginning, the real-time video processing using the video camera sends a real-time video signals of the [^{18}F]-FDG volume in the 5-ml syringe to the computer. Next the computer is processes the image of the 5-ml syringe using a computer vision system toolbox for image processing. The Region of Interest (ROI) is used in selecting a view of the scale on the 5-ml syringe with red color background. The color space conversion converts RGB color space to intensity the image, the median filter is used for noise filtering. Next converts label matrix into RGB image and converts RGB color space to intensity the image. Finally, the pixel of white-color is counted and calculated for detecting the volume to send digital signal output fedback to the Arduino Uno R3 in order to control the micro air pump using the L293D dc motor controller and consequently the computer screen displays the real-time volume of [^{18}F]-FDG in the 5-ml syringe inside the manipulation cell.

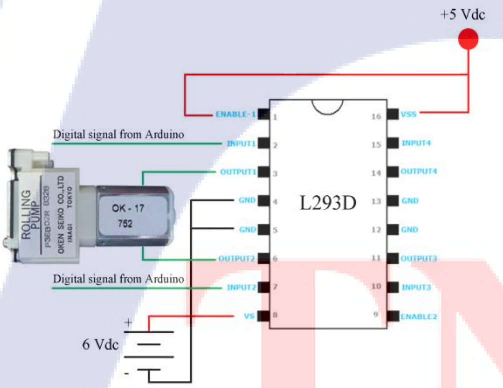

Fig. 4. Diagram of volume controller for experimental set-up and demonstrations.

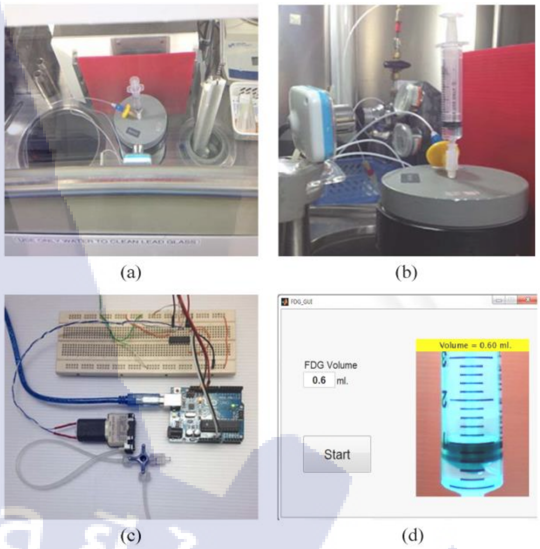

Fig. 5. Photographs of experimental set-up and demonstrations; (a) the original beveling view of a manipulation cell that is visible for the operator, (b) the proposed video camera with close distance, (c) the prototype of the proposed system, (d) the GUI of the proposed system.

The main feature of the proposed video processing techniques is the real-time control and monitoring of [^{18}F]-FDG volume automatically and it is no longer needed to measure by eye approximation.

Figure 4 shows the diagram of the volume controller for experimental set-up and demonstrations. The digital signal output fedback to the Arduino Uno R3 in order to control the micro air pump using the L293D dc motor controller.

III. Experimental Results and Discussions

Figure 5 shows the photographs of experimental set-up during demonstrations. It can be seen in Fig.5 (a) that the original beveling view (approximately 45 Degree) of the manipulation cell that is visible for the operator is relatively difficult to dispense [^{18}F]-FDG. Therefore, the operator must have high skill in approximating the volume of [^{18}F]-FDG in a syringe. Fig.5 (b) shows the proposed video camera with close distance of 6 cm. in reading the level of [^{18}F]-FDG in a syringe. Fig.5 (c) shows the prototype of the proposed system (the volume controller) where operator can dispense [^{18}F]-FDG outside the manipulation cell. Fig.5 (d) shows the GUI of the proposed system.

Figure 6 depicts the photographs of a 5-ml syringe that is visible for the operator at different level of dispensing [^{18}F]-FDG; with a step of 0.2 ml.. It can be seen from Fig.6 that the visible syringe is large and no longer bevel. This helps the operator to read the scale easily. As illustrated in Fig.6, the entire syringe plunger is located at the exact location on the syringe and the calculated volume can be read easily.

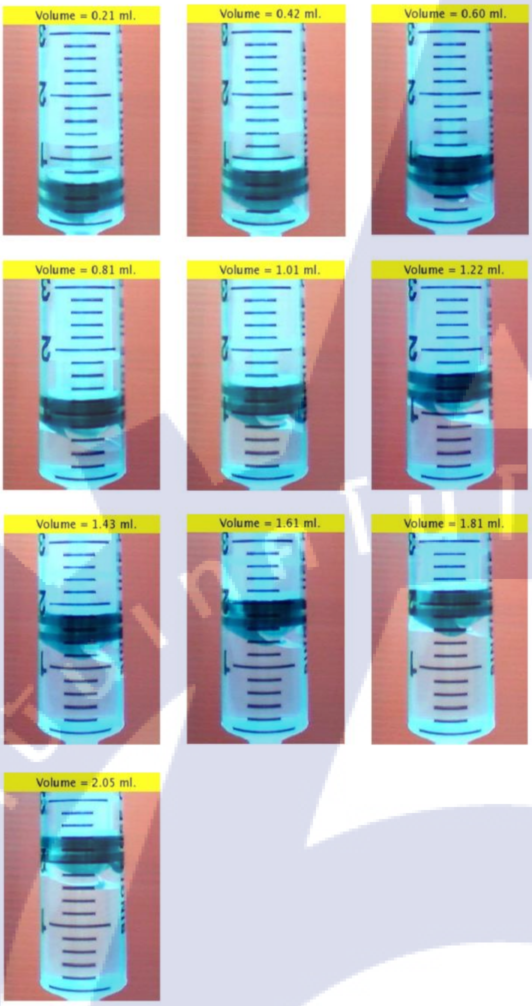

Fig. 6. Photographs of a 5-ml syringe that is visible for the operator at different level of dispensing [^{18}F]-FDG with a step of 0.2 ml..

It can be considered that the radiopharmaceutical dispensing with real-time video processing technique using the video camera can enhance the operator to dispense radiopharmaceutical effectively. The precision of the required volume and the vision would be better manual operation. The operator can simply dispense the [^{18}F]-FDG volume at only one-time operation, especially in case of low required volume, i.e. high concentration. In addition, the operator can control the required volume outside the manipulation cell by GUI with high precision. In terms of accuracy, Table 1 summarizes the comparison between the required volume and the measured volume using the proposed video processing technique with

TABLE I. COMPARISONS OF THE REQUIRED VOLUME AND THE MEASURED [^{18}F]- FDG VOLUME USING THE PROPOSED TECHNIQE.

Required Volume (ml.)	Minimum - Maximum of Measured Volume (ml.)	Maximum Percentage of Errors (%)
0.2	0.19 - 0.21	5
0.4	0.38 - 0.42	5
0.6	0.59 - 0.62	3
0.8	0.78 - 0.82	2.5
1	0.98 - 1.03	3
1.2	1.19 - 1.22	1.7
1.4	1.38 - 1.43	2.1
1.6	1.57 - 1.62	1.9
1.8	1.77 - 1.83	1.7
2	1.98 - 2.05	2.5

an automated volume controller. It can be considered from Table 1 that the maximum error is at 5% which is a percent error or difference of less than 10% will be acceptable, proving more efficient than using manual dispensing whit a direct eye sight. Therefore, the precision of required [^{18}F]-FDG dose is no longer based on operator's skills. Moreover, this technique can reduced radiation exposures with cost-effective implementation.

IV. CONCLUSIONS

The research aims to integrate of knowledge on image processing in the computer engineering field to enhance the nuclear medicine in the medical field. A fully automated radiopharmaceutical dispenser is relatively costly whilst a manual dispenser is harmful to operators caused by radiation exposures. Hence, the research could develop a cost-effective radiopharmaceutical dispenser with real-time video processing system. The proposed system employs the video camera sending the real-time video signals of the [^{18}F]-FDG volume in the 5-ml syringe to a computer, enlarging syringe volume display by a video processing based on MATLAB. The volume control was done by air flowing slowly through an extension tube from the micro air pump to the [^{18}F]-FDG vial until the 5-ml syringe plunger is moved to obtain the required volume automatically. The computer displays an automated calculation volume of [^{18}F]-FDG to help the operator and to enhance better visualization of [^{18}F]-FDG volume. Therefore, only once operation is sufficient for radiopharmaceutical preparation. Finally, the developed approach could offer a solution to high-cost commercial radiopharmaceutical dispenser, obtain a high precision, and reduce operator's radiation exposure.

ACKNOWLEDGEMENTS

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The Realization of Real-Time Video Processing for Volume Measurement in Radiopharmaceutical Dispenser

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***Abstract*—This paper presents the realization of a cost-effective semi-auto radiopharmaceutical dispenser with real-time video processing for volume measurement. Typically, a fully-automated radiopharmaceutical dispenser is expensive while a manual dispenser is harmful to operators due to radiation exposures. In the proposed system, the video camera provides the real-time video signals of the Fluorodeoxyglucose ([^{18}F]-FDG) volume in a 5-ml syringe to a computer and the volume detection is subsequently performed through video processing using MATLAB. Air is slowly pushed through an extension tube from a 20-ml syringe to the [^{18}F]-FDG vial until the 5-ml syringe plunger is moved to reach the required volume. The computer subsequently displays an automated calculation volume of [^{18}F]-FDG for the operator that help a dispensing of the [^{18}F]-FDG and therefore a one-time operation is sufficient. The proposed system offers a potential alternative to high-cost commercial radiopharmaceutical dispenser achieving a high precision and reducing operator's radiation exposure.**

Keywords*—Radiopharmaceutical Dispenser; Real-Time Video Processing; Volume Measurement

I. Introduction

Nuclear medicine is a medical specialty that includes applications in radioactive substances in disease diagnosis and treatment processes. The Fluorodeoxyglucose, which is also commonly abbreviated [^{18}F]-FDG and generally utilized Positron Emission Tomography (PET) radiopharmaceutical is regularly prepared using an automated synthesizer. Uptaking the [^{18}F]-FDG by human tissues is an indication for the tissue uptake of glucose that is closely correlated with certain types of tissue metabolism [1]. Consequently, the PET scanner can proceed either two-dimensional or three-dimensional images of the distribution of [^{18}F]-FDG throughout the patient body after the injection of [^{18}F]-FDG. Figure 1 illustrates the Medullary Thyroid Carcinoma (MTC) patient with uptake on [^{18}F]-FDG] [2]. In the preparation process of the [^{18}F]-FDG, nuclear medicine operators such as pharmacist, nurse, chemist, and doctor would certainly receive a radiation burden to the whole body and hands resulting from preparing radiopharmaceutical doses and also administration of patient doses and contact.

As multiple doses of [^{18}F]-FDG are dispensed from a single production over eight hours, an automated dispenser is needed to reduce the operator's radiation exposure [3]. Despite the fact that numerous automated dispensers are commercially available for [^{18}F]-FDG that are available in the form of vials or syringes, those automated dispensers are relatively costly. However, the preparation of [^{18}F]-FDG in practice in many hospitals are using manual operation for small amount of [^{18}F]-FDG dispenser for economic reasons. In the case where manual operations are considered, there has been a report of a simple device for dispensing [^{18}F]-FDG from Jong O Park and et al. [4] that realizes the vial-to-vial technique using an airflow to control the volume of [^{18}F]-FDG in order to decrease chances to receive a radiation exposures to the whole body and hands.

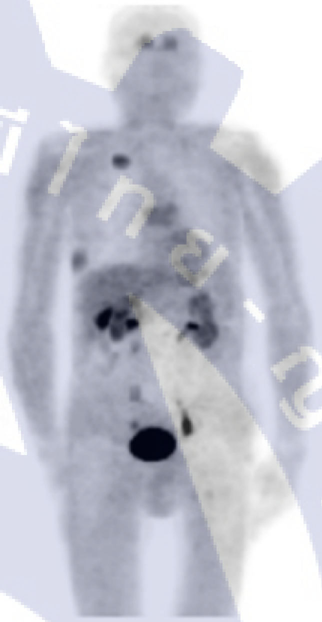


Fig. 1. Illustration of MTC patient with uptake on [^{18}F]-FDG.

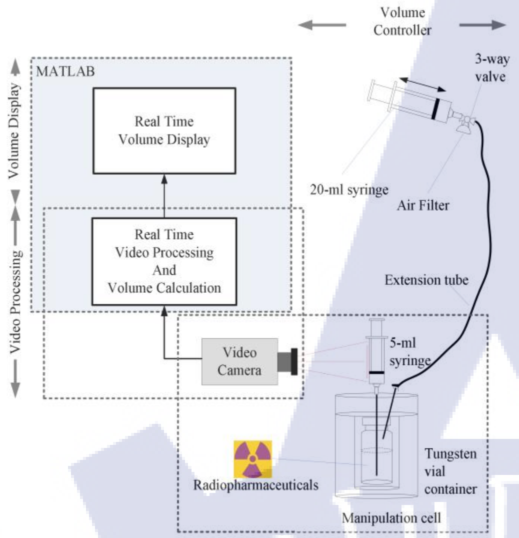


Fig. 2. Diagram of the proposed the realization of real-time video processing for volume mesurement in radiopharmaceutical dispenser.

As the volume of [18F]-FDG is very little before diluting through saline solution, the accuracy for [18F]-FDG dispenser in [4] dose is only based on operator's skills and the operators have to use hands to check the volume of [18F]-FDG several times using a standard radioactive device measurement tools, which ultimately increase chances to expose receive the radioactive. Therefore, this paper aims to decrease the chances for nuclear medicine operators to expose radiation by using video processing technique. The proposed system employs the cost-effective video camera that sends a real-time video signals of the [18F]-FDG volume in the 5-ml syringe to a computer. The [18F]-FDG volume is detected and the image quantity is then enhanced through video processing using MATLAB. Air is slowly pushed through an extension tube from the 20-ml syringe to the [18F]-FDG vial until the 5-ml syringe is moved to reach the total required volume. The computer subsequently displays the 5-ml syringe image with automated calculation volume of [18F]-FDG to enhance the operator vision of volume of [18F]-FDG. It should be noted that only one-time operation is sufficient. It would achieve a high-cost commercial radiopharmaceutical dispenser as a high precision, so that the operator's radiation exposure can also be reduced.

II. Proposed Radiopharmaceutical Dispenser using Real-Time Video Processing

A. Experimental Apparatus

Figure 2 is the diagram of the proposed radiopharmaceutical dispenser with real-time video processing. The diagram depicts the vial-to-syringe [18F]-FDG dispensing device placed in a manipulation cell. The [18F]-FDG dispensing device is composed of a [18F]-FDG vial, a long needle (18G, 90 mm.), a short needle (20G, 38 mm.), the 5-ml syringe, an extension tube (0.9 mm i.e., 1000 mm length), the 20-ml syringe, the three-way stopcock, the video camera, the computer with MATLAB, and the sterile air filter (0.20 µm) [4].The 5-ml syringe with a long needle is put into the [18F]-FDG vial in a tungsten vial container. One of the ports is marginally open to allow accessing to the extension tube. A disposable 20-ml syringe is located outside the manipulation cell and connected to the [18F]-FDG vial through the three-way stopcock, the extension tube, and the sterile air filter is enclosed to the vent port of the three-way stopcock. The required volume for an individual dose is calculated from the total radioactivity and the volume of [18F]-FDG (Concentration) in the [18F]-FDG vial.

The required volume of [18F]-FDG has been dispensed from the [18F]-FDG vial, the required volume of [18F]-FDG in the 5-ml syringe will be approximately 0.2 to 2.6 ml. so that after the 5-ml syringe is filled with normal saline. The filled 5-ml syringe is attached to a long needle that has been inserted into the bottom of the [18F]-FDG vial. The three-way stopcock is then positioned toward the 20-ml syringe and the [18F]-FDG vial. Air is slowly pushed through the extension tube from the 20-ml syringe, and then push the [18F]-FDG in the vial. The [18F]-FDG in the vial has been transferred until the 5-ml syringe plunger is moved upward to reach the required volume.

The real-time video processing of the 5-ml syringe plunger showing the 5-ml syringe plunger is moved upward to reach the required volume during the [18F]-FDG dispensing from the [18F]-FDG to the 5-ml syringe on the computer screen. After dispensing the three-way stopcock handle is rotated to block the three-way ports, the 5-ml syringe is then manually removed from the [18F]-FDG vial, filled with the normal saline. The total injection volume in the 5-ml syringe will be 3 to 4 ml. and ready for delivery to the patient.

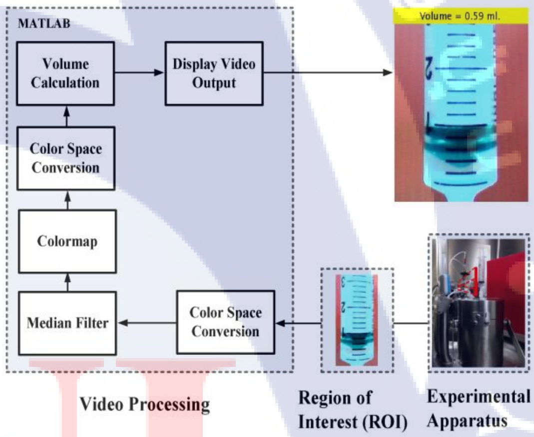
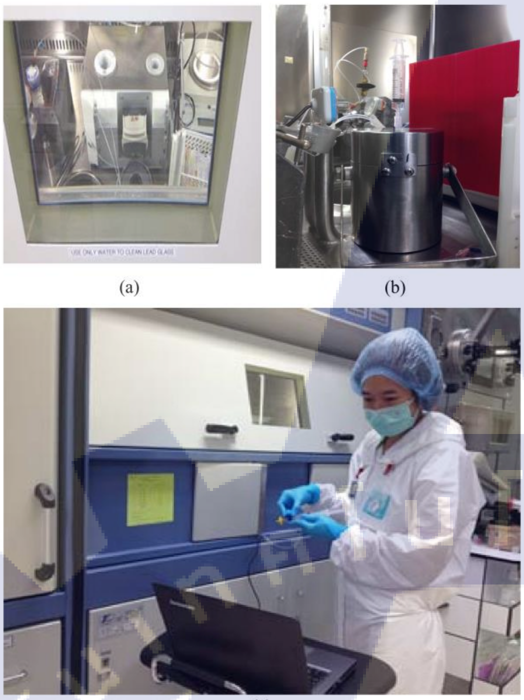


Fig. 3. Diagram of overall operation procedures through video processing technique, showing the region of interest (ROI), video processing in MATLAB and output capture.



(a) (b) (c)

Fig. 4. Photographs of experimental set-up and demonstrations; (a) The original beveling view of a manipulation cell that is visible for the operator, (b) the proposed video camera with close distance, (c) the illustration of actual operation using the proposed system.

B. *Video Processing Technique*

Figure 3 shows the diagram of overall operation procedures through video processing technique; the Region of Interest (ROI), video processing in MATLAB and output capture. At the beginning, the real-time video processing using the video camera sends a real-time video signals of the [^{18}F]-FDG volume in the 5-ml syringe to the computer. Next the computer is processes the image of the 5-ml syringe using a computer vision system toolbox for image processing.

The Region of Interest (ROI) is used in selecting a view of the scale on the 5-ml syringe with red color background. The color space conversion converts RGB color space to intensify the image. A median filter is used for noise filtering. Next converts label matrix into RGB image and converts RGB color space to intensity the image. Finally, the pixel of white-color is counted and calculated for detecting the volume and consequently the computer screen displays the real-time volume of [^{18}F]-FDG in the 5-ml syringe inside the manipulation cell. The main feature of the proposed video processing techniques is the real-time monitoring of [^{18}F]-FDG volume automatically and it is no longer needed to measure by eye approximation or weight measurements.

III. Experimental Results and Discussions

Figure 4 shows the photographs of experimental set-up during demonstrations. It can be seen in Figure 4 (a) that the original beveling view (approximately 45 Degree) of the manipulation cell that is visible for the operator is relatively difficult to dispense [^{18}F]-FDG. Therefore, the operator must have high skill in approximating the volume of [^{18}F]-FDG in a syringe. Figure 4 (b) shows the proposed video camera with close distance of 6 cm. in reading the level of [^{18}F]-FDG in a syringe. Figure 4 (c) illustrates the actual operation using the proposed system where operator can dispense [^{18}F]-FDG outside the manipulation cell.

Figure 5 depicts the photographs of a 5-ml syringe that is visible for the operator at different level of dispensing [^{18}F]-FDG with a step of 0.2 ml.. It can be seen from Figure 5 that the visible syringe is large and no longer bevel. This helps the operator to read the scale easily. As illustrated in Figure 5, the entire syringe plunger is located at the exact location on the syringe and the calculated volume can be read easily.

TABLE I. Comparisons of the actual volume and the measured [^{18}F]-FDG volume using the proposed technique.

Actual Volume (ml.)	Measured Volume (ml.)	Percentage of Errors (%)
0.2	0.19	5
0.4	0.43	7.5
0.6	0.62	3.3
0.8	0.82	2.5
1	1.06	6
1.2	1.23	2.5
1.4	1.42	1.43
1.6	1.58	1.25
1.8	1.79	0.5
2	2.04	2

It can be considered that the radiopharmaceutical dispensing with real-time video processing technique using the video camera can enhance the operator to dispense radiopharmaceutical effectively. The precision of the required [^{18}F]-FDG volume and the vision would be better manual operation. The operator can simply dispense the [^{18}F]-FDG volume at only one-time operation, especially in case of low required [^{18}F]-FDG volume, i.e. high concentration. In addition, the operator can control the required [^{18}F]-FDG volume outside the manipulation cell with high precision. In terms of accuracy, Table 1 summarizes the comparison between the actual volume and the measured volume using the proposed video processing technique. It can be considered from Table 1 that the maximum error is at approximately 7.5% which is acceptable, proving more efficient than using a direct eye sight. Therefore, the precision of required [^{18}F]-FDG dose is no longer based on operator's skills. Moreover, this technique can reduced radiation exposures with cost-effective implementation. In the future perspective, the real-time video processing technique with the radiopharmaceutical dispensing

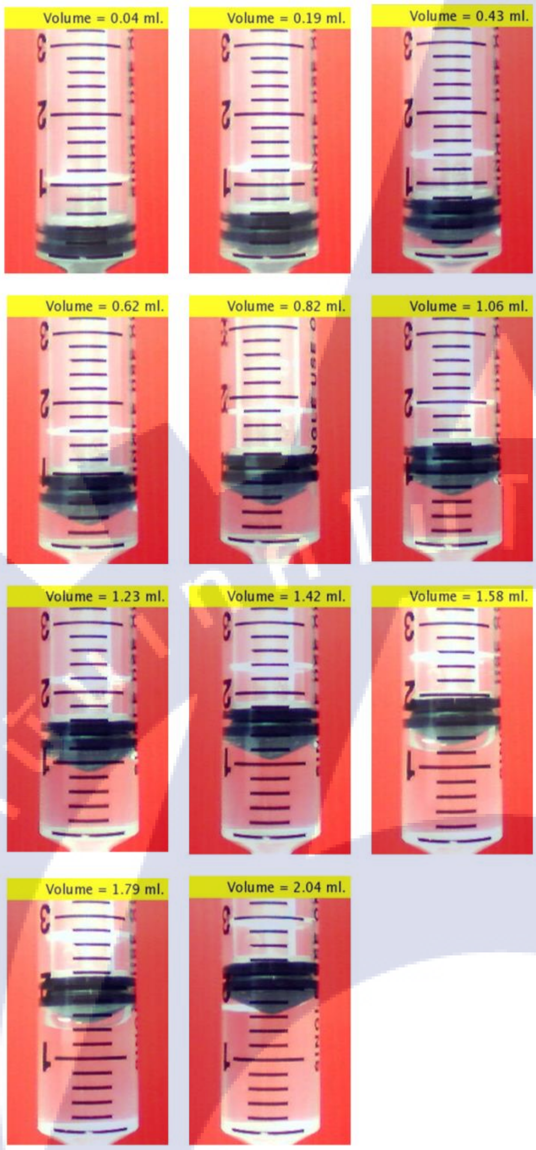


Fig. 5. Photographs of a 5-ml syringe that is visible for the operator at different level of dispensing [^{18}F]-FDG with a step of 0.2ml.

manual methods will help to develop an automated calculation volume of [^{18}F]-FDG using microcontroller and small motor.

IV. Conclusions

The research aims to integrate of knowledge on image processing in the computer engineering field to enhance the nuclear medicine in the medical field. A fully automated radiopharmaceutical dispenser is relatively costly whilst a manual dispenser is harmful to operators caused by radiation exposures. Hence, the research could develop a cost-effective radiopharmaceutical dispenser with real-time video processing system. The proposed system employs the video camera sending the real-time video signals of the [^{18}F]-FDG volume display, by a video processing based on MATLAB. The volume control was done by air flowing slowly through an extension tube from the 20-ml syringe to the [^{18}F]-FDG vial until the 5-ml syringe plunger is moved, to obtain the required total [^{18}F]-FDG volume. The computer displays a measured volume of [^{18}F]-FDG in order to help the operator and to enhance better visualization of [^{18}F]-FDG volume. Therefore, only one time operation is sufficient for radiopharmaceutical preparation. Finally, the developed approach could offer a solution to high-cost commercial radiopharmaceutical dispenser, obtain a high precision, and reduce operator's radiation exposure.

Acknowledgments

The authors are grateful to Oncology Imaging and Nuclear Medicine, Wattanosoth Hospital, Bangkok Medical Center for facilities in experiments. The authors would also like to thank Ms.Suthatip Ngokpol, a radiochemist, for her helps on dispense [^{18}F]-FDG. The authors also acknowledge the Research and Academic Services Division of Thai-Nichi Institute of Technology (TNI) for financial supports.

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A Cost-Effective Radiopharmaceutical Dispenser with Real-Time Video Processing

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***Abstract*—this paper presents the development of a cost-effective radiopharmaceutical dispenser with real-time video processing. Typically, a fully-automated radiopharmaceutical dispenser is expensive while a manual dispenser is harmful to operators due to radiation exposures. In the proposed system, the video camera sends the real-time video signals of the Fludeoxyglucos ([^{18}F]-FDG) volume in a 5-ml syringe to a computer and the volume detection is subsequently performed through video processing using MATLAB Simulink. Air is slowly pushed through an extension tube from a 20-ml syringe to the [^{18}F]-FDG vial until the 5-ml syringe is moved to reach the total [^{18}F]-FDG required volume. The computer subsequently displays high-quality image for the operator that help a better vision of an amount of [^{18}F]-FDG and therefore a one-time operation is sufficient. The proposed system offers a potential alternative to high-cost commercial radiopharmaceutical dispenser achieving a high precision and reducing operator's radiation exposure.**

Keywords*—*Radiopharmaceutical Dispenser Semi-Automation, Real-Time Video Processing

I. INTRODUCTION

Nuclear medicine is a medical specialty that includes applications in radioactive substances in disease diagnosis and treatment processes. The Fludeoxyglucose, which is also commonly abbreviated [^{18}F]-FDG and generally utilized Positron Emission Tomography (PET) radio-pharmaceutical or Magnetic Torquer Coil (MTC), is regularly prepared using an automated synthesizer. Uptaking the [^{18}F]-FDG by human tissues is an indication for the tissue uptake of glucose that is closely correlated with certain types of tissue metabolism [1]. Consequently, the PET scanner can proceed either two-dimensional or three-dimensional images of the distribution of [^{18}F]-FDG throughout the patient body after the injection of [^{18}F]-FDG. Fig.1 illustrates the MTC patient with uptake on [^{18}F]-FDG showing areas with cancers in human body [2]. In the preparation process of the [^{18}F]-FDG, nuclear medicine operators such as pharmacist, nurse, chemist, and doctor would certainly receive a radiation burden to the whole body and hands resulting from preparing radiopharmaceutical doses and also administration of patient doses and contact.

Fig.1. Illustration of MTC patient with uptake on [^{18}F]-FDG showing areas with cancers in human body [2].

As multiple doses of [^{18}F]-FDG are dispensed from a single production over eight hours, an automated dispenser is needed to reduce the operator's radiation exposure [3]. Despite the fact that numerous automated dispensers are commercially available for [^{18}F]-FDG that are available in the form of vials or syringes, those automated dispensers are relatively costly. However, the preparation of [^{18}F]-FDG in practice in many hospitals are using manual operation for small amount of [^{18}F]-FDG dispenser for economic reasons. In the case where manual operations are considered, there has been a report of a simple device for dispensing [^{18}F]-FDG from Jong O Park and et al. [4] that realizes the vial-to-vial technique using a laminar airflow to control the amount of [^{18}F]-FDG in order to decrease chances to receive a radiation exposures to the whole body and hands.

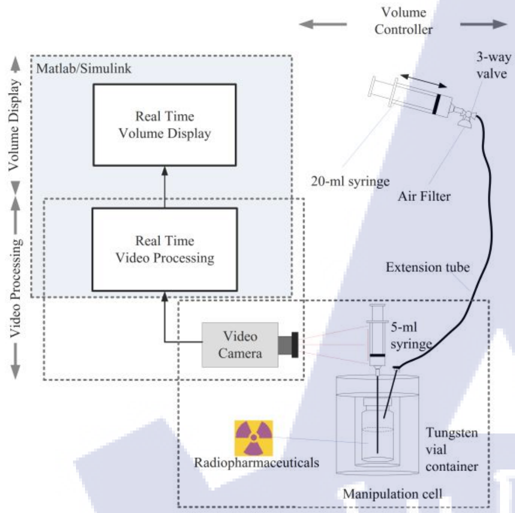


Fig.2. Diagram of the proposed semi-automated radiopharmaceutical dispenser with real-time video processing.

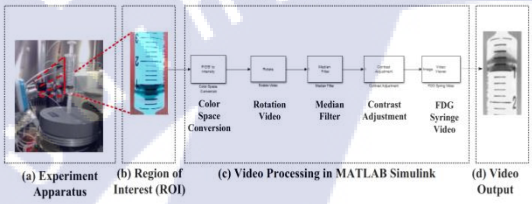


Fig.3. Diagram of overall operation procedures through video processing technique, showing the region of interest (ROI), video processing in MATLAB Simulink and output capture.

As the amount of [^{18}F]-FDG is very little before diluting through saline solution, the accuracy for [^{18}F]-FDG dispenser in [4] dose is only based on operator's skills and the operators have to use hands to check the amount of [^{18}F]-FDG several times using a standard radioactive device measurement tools, which ultimately increase chances to expose receive the radioactive.

Therefore, this paper aims to decrease the chances for nuclear medicine operators to expose radiation by using video processing technique. The proposed system employs the video camera that sends a real-time video signals of the [^{18}F]-FDG volume in the 5-ml syringe to a computer and the image quantity is then enhanced through video processing using MATLAB Simulink. Air is slowly pushed through an extension tube from the 20-ml syringe to the [^{18}F]-FDG vial until the 5-ml syringe is moved to reach the total required volume. The computer subsequently displays high-quality image to enhance the operator vision of an amount of [^{18}F]-FDG. It should be noted that only one-time operation is sufficient. It would achieve a high-cost commercial radiopharmaceutical dispenser as a high precision, so that the operator's radiation exposure can also be reduced.

II. Proposed Radiopharmaceutical Dispenser using Real-Time Video Processing

A. *Experiemntal Apparatus*

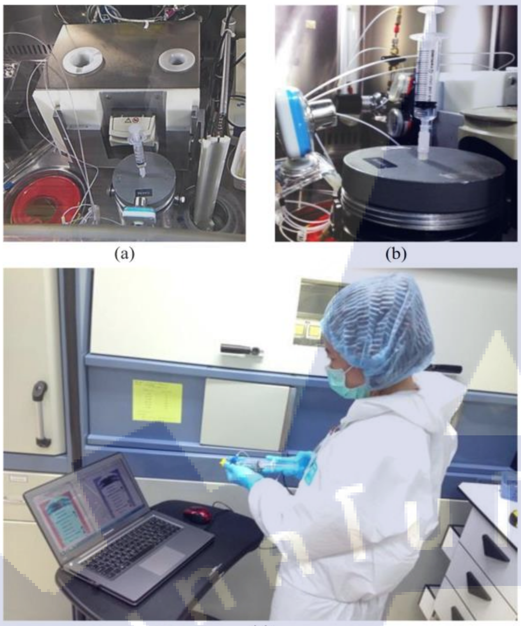
Fig.2 is the diagram of the proposed radiopharmaceutical dispenser with real-time video processing. The diagram depicts the vial-to-syringe [^{18}F]-FDG dispensing device placed in a manipulation cell. The [^{18}F]-FDG dispensing device is composed of a [^{18}F]-FDG vial, a long needle (18G, 90 mm.), a short needle (20G, 38 mm.), the 5-ml syringe, an extension tube (0.9 mm i.e., 1000 mm length), the 20-ml syringe, the three-way stopcock, the video camera, the computer with MATLAB Simulink, and the sterile air filter (0.20 µm) [4].The 5-ml syringe with a long needle is put into the [^{18}F]-FDG vial in a tungsten vial container. One of the ports is marginally open to allow accessing to the extension tube.

A disposable 20-ml syringe is located outside the manipulation cell and connected to the [^{18}F]-FDG vial through the three-way stopcock, the extension tube, and the sterile air filter is enclosed to the vent port of the three-way stopcock. The required volume for an individual dose is calculated from the total radioactivity and the volume of [^{18}F]-FDG (Concentration) in the [^{18}F]-FDG vial. The 5-ml syringe is filled with normal saline so that after the required volume of [^{18}F]-FDG has been dispensed from the [^{18}F]-FDG vial the total volume in the syringe will be 3 to 4 ml. The filled 5-ml syringe is attached to a long needle that has been inserted into the bottom of the [^{18}F]-FDG vial. The three-way stopcock is then positioned toward the 20-ml syringe and the [^{18}F]-FDG vial. Air is slowly pushed through the extension tube from the 20-ml syringe, and then push the [^{18}F]-FDG in the vial. The [^{18}F]-FDG in the vial has been transferred until the 5-ml syringe plunger is moved upward to reach the required volume.

The real-time video processing of the 5-ml syringe plunger showing the 5-ml syringe plunger is moved upward to reach the required volume during the [^{18}F]-FDG dispensing from the [^{18}F]-FDG to the 5-ml syringe on the computer screen. After dispensing the three-way stopcock handle is rotated to block the three-way ports, the 5-ml syringe is then manually removed from the [^{18}F]-FDG vial, filled with the normal saline. The total volume in the 5-ml syringe will be 3 to 4 ml and ready for delivery to the patient.

B. *Video Processing Technique*

Fig.3 shows the diagram of overall operation procedures through video processing technique; the Region of Interest (ROI), video processing in MATLAB Simulink and output capture. At the beginning, the real-time video processing using the video camera sends a real-time video signals of the [^{18}F]-FDG volume in the 5-ml syringe to the computer. Next the computer is processes the image of the 5-ml syringe using a Simulink computer vision system toolbox for image processing. The Region of Interest (ROI) is used in selecting a view of the scale on the 5-ml syringe. The color space conversion converts RGB color space to intensify the image,



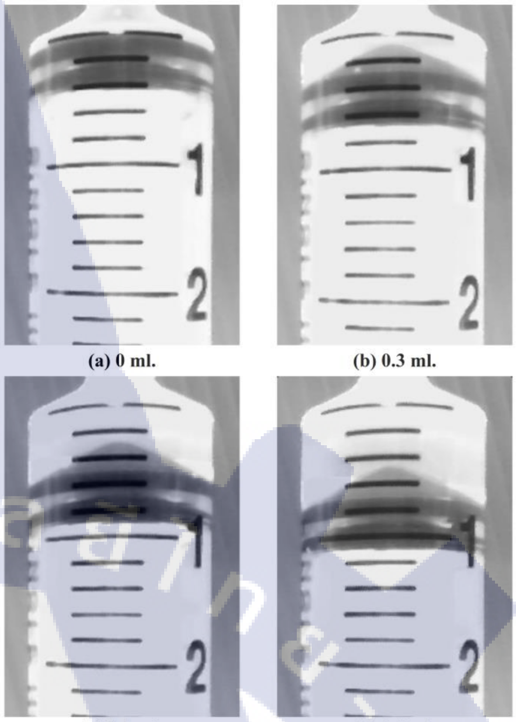
(a) (b) (c)

Fig.3. Photographs of experimental set-up and demonstrations; (a) The original beveling view of a manipulation cell that is visible for the operator, (b) the proposed video camera with close distance, (c) the illustration of actual operation using the proposed system.

the image rotation is used for rotating the 5-ml syringe image for a better view. A median filter block is used for noise filtering and a contract adjustment block, to adjust contract of the 5-ml syringe image. Finally, the computer screen displays the real-time video processing of the 5-ml syringe inside the manipulation cell.

III. Experiemntal Results and Discussions

Fig.3 shows the photographs of experimental set-up during demonstrations. It can be seen in Fig.3 (a) that the original beveling view (approximately 45 Degree) of the manipulation cell that is visible for the operator is relatively difficult to dispense [^{18}F]-FDG. Therefore, the operator must have high skill in approximating the amount of [^{18}F]-FDG volume in a syringe. Fig.3 (b) shows the proposed video camera with close distance of 6 cm. in reading the level of [^{18}F]-FDG in a syringe. Fig. 3 (c) illustrates the actual operation using the proposed system where operator can dispense [^{18}F]-FDG outside the manipulation cell. Fig.4 depicts the photographs of a 5-ml syringe that is visible for the operator at different level of dispensing [^{18}F]-FDG; (a) Non-dispensing level (or 0 ml.), (b) 0.3 ml., (c) 0.5 ml., and (d) 0.7 ml.. It can be seen from Fig.4 that the visible syringe is large and no longer bevel. This helps the operator to read the scale easily. As illustrated in Fig.4, the entire syringe plunger is located at the exact location on the syringe and can be read easily.



(a) 0 ml. **(b) 0.3 ml.** **(c) 0.5 ml.** **(d) 0.7 ml.**

Fig.4. Photographs of a 5-ml syringe that is visible for the operator at different level of dispensing [^{18}F]-FDG; (a) Non-dispensing level (or 0 ml.), (b) 0.3 ml., (c) 0.5 ml., and (d) 0.7 ml..

It can be considered that the radiopharmaceutical dispensing with real-time video processing technique using the video camera can enhance the operator to dispense radiopharmaceutical effectively. The precision of the required [^{18}F]-FDG volume and the vision would be better manual operation. The operator can simply dispense the [^{18}F]-FDG volume at only one-time operation, especially in case of low required [^{18}F]-FDG volume, i.e. high concentration. In addition, the operator can control the required [^{18}F]-FDG volume outside the manipulation cell with high precision. Therefore, the precision of required [^{18}F]-FDG dose is no longer based on operator's skills. Moreover, this technique can reduced radiation exposures with cost-effective implementation. In the future perspective, the real-time video processing technique with the radiopharmaceutical dispensing manual methods will help to develop an automated calculation volume of [^{18}F]-FDG using microcontroller and small motor.

IV. Conclusion

The research aims to integrate of knowledge on image processing in the computer engineering field to enhance the nuclear medicine in the medical field. A fully automated radiopharmaceutical dispenser is relatively costly whilst a manual dispenser is harmful to operators caused by radiation exposures. Hence, the research could develop a cost-effective radiopharmaceutical dispenser with real-time video processing system. The proposed system employs the video camera sending the real-time video signals of the [^{18}F]-FDG volume in the 5-ml syringe to a computer, enlarging syringe volume display, by a video processing based on MATLAB Simulink. The volume control was done by air flowing slowly through an extension tube from the 20-ml syringe to the [^{18}F]-FDG vial until the 5-ml syringe is moved, to obtain the required total [^{18}F]-FDG volume. The computer displays high-quality image afterwards to help the operator and to enhance better visualization of [^{18}F]-FDG amount. Therefore, only once operation is sufficient for radiopharmaceutical preparation. Finally, the developed approach could offer a solution to high-cost commercial radiopharmaceutical dispenser, obtain a high precision, and reduce operator's radiation exposure.

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The authors are grateful to Oncology Imaging and Nuclear Medicine, Wattanosoth Hospital, Bangkok Medical Center for facilities in experiments. The authors would like also to thank Ms.Suthatip Ngogpol, a radiochemist, for her helps on dispense [^{18}F]-FDG. The authors also acknowledge the Researchand Academic ServicesDevision of Thai-Nichi Institute of Technology (TNI) for financial supports.

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