CARDIOVASCULAR CONTROL SYSTEM (DURING ANESTHESIA) USING MATLAB

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To my parent, parent in law, brothers, sisters

and especially my wife, Mimi Rahayu binti Hamdin

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ABSTRACT

In a modern operating room, the depth of anesthesia is the responsibility of the anesthetist/anesthesiologist who controls many other vital parameters, such as blood pressure, respiration, heart rate, temperature, blood oxygenation, and exhaled carbon dioxide, within acceptable bounds. Any assistance that the anesthetist/anesthesiologist can obtain automatically will increase safety margins by allowing increased attention to other functions, which not so easily automated. Clearly, patient safety is the ultimate attention of the anesthetist/anesthesiologist. Regarded to this matter, the objective of this project is to design an automated system to regulate the depth of anesthesia. Mean Arterial Pressure (MAP) is regarded as a reliable measure of the depth of anesthesia or in another way, the level of MAP can determine proportionally as guide to the level of inhaled anesthetic of a particular patient. Therefore, the controlled variable will be the measured MAP. As per the objective, MAP will be regulate to any desired set point and maintain the set point in the presence of unwanted disturbances. The closed-loop system will respond rapidly and smoothly to changes in the MAP set point without excessive overshoot. It will also minimize the effect of unwanted disturbances, such as, surgical disturbances due to skin incisions and measurement noise. Finally, the system must be applicable to many different patients. Control specifications of this system will be based on clinical experience of the patient such as settling time and percent overshoot.

ABSTRAK

Di dalam bilik pembedahan yang moden, sejauh mana tahap pra-sedar seseorang pesakit itu adalah bergantung kepada pakar yang mengawal parameter-parameter yang berkadar langsung dengan tahap pra-sedar ini seperti tekanan darah, sistem pernafasan, suhu, peredaran oksigen, kadar degupan jantung agar berada dalam jangkaan yang boleh diterima. Akan tetapi, terdapat beberapa parameter yang agak sukar untuk dikawal dan sekiranya satu sistem dapat dicipta yang boleh menolong pakar dalam mengawal parameter-parameter tersebut, sudah pasti tahap keselamatan dapat ditingkatkan. Memang tidak dinafikan bahawa keselamatan pesakit adalah tujuan utama pakar. Merujuk kepada kepentingan ini, objektif projek ini adalah untuk mencipta satu sistem automatik dalam mengawal tahap pra-sedar seseorang pesakit. Tekanan arteri purata(MAP) adalah salah satu ukuran untuk menentukan sejauh mana tahap pra-sedar seseorang pesakit. Dengan itu, projek ini akan menjadikan tekanan arteri purata(MAP) sebagai parameter kawalan di mana ia akan dikawal kepada satu nilai yang telah ditetapkan dan tetap berada di tahap itu walaupun dengan kehadiran gangguan luar. Di dalam projek ini, satu sistem gelung tertutup akan dicipta di mana ia akan bertindak secara pantas, lancar dan tidak melebihi tahap yang telah ditetapkan apabila nilai Tekanan arteri purata(MAP) berubah dari satu nilai ke satu nilai. Sistem juga perlu berubah secara minimum dengan kehadiran gangguan luar dan akhir sekali ia boleh digunakan untuk pesakit yang berada dalam pelbagai situasi. Spesifikasi kawalan untuk sistem ini adalah berpandukan kepada pengalaman klinik tentang pesakit.

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CHAPTER I

INTRODUCTION

The cardiovascular system consists of three anatomical components, which are the autonomic nervous system, the heart, and the vasculature. These three components interact in a complex manner to control blood flow to organs throughout the body. A clear understanding of the basic principles of cardiovascular physiology is needed to appreciate the complex steps of regulation blood pressure.

1.1 The Autonomic Nervous System

The autonomic nervous system is widely distributed throughout the body and controls a variety of bodily functions, including blood pressure and heart rate. The efferent peripheral autonomic nervous system is composed of two opposing subsystems, the sympathetic nervous system and the parasympathetic nervous system.

1.1.1 Sympathetic Nervous System

The sympathetic nervous system is diffuse and innervates many components of the cardiovascular system. The primary neurotransmitter of postganglionic sympathetic nerve fibers is norepinephrine (also referred to as noradrenaline); these fibers are known as adrenergic fibers. The adrenal medulla is also a component of the sympathetic nervous system that is analogous to postganglionic sympathetic nerve fibers. Instead of norepinephrine, the adrenal medulla releases epinephrine (adrenaline). The target organs of the sympathetic nervous system contain receptors for norepinepherine and epinephrine; these receptors are known as adrenergic receptors. Next is a list of important target organs of the symphathetic nervous system, the response of the organ to sympathetic stimulation, and the specific adrenergic receptor subtypes found on these target organs.

- Vascular smooth muscle (increased contraction of skin, renal, splanchnic, skeletal muscle blood vessels via alpha-adrenergic receptors, increased relaxation of skeletal muscle blood vessels via $beta_2$-adrenergic receptors)
- Heart (increased contractility via $beta_1$-adrenergic and $beta_2$-adrenergic; increased heart rate via $beta_1$-adreneregic)
- Kidney (increased renin release -- $beta_1$-adrenergic)
- Bronchiolar smooth muscle (increased relaxation -- $beta_2$-adrenergic)

1.1.2 Parasympathetic Nervous System

The parasympathetic nervous system innervation of the cardiovascular system is essentially just the innervation of the heart by the vagus nerve. This innervation is relatively discrete, being limited to the sino-atrial (SA) node (pacemaker) and the atrioventricular (AV) junction. There is little or no innervation of the cardiac ventricles or blood vessels, although acetylcholine released by the parasympathetic nervous system can bind to receptors in the endothelium (the cells that line blood vessels) causing the release of EDRF (Endothelium Derived Relaxing Factor) which relaxes vascular smooth muscle. The postganglionic neurotransmitter of the parasympathetic nervous system is acetylcholine. Acetylcholine released by the parasympathetic nervous system binds to muscarinic cholinergic receptors on target tissues. Next is a list of cardiovascular targets of the parasympathetic nervous system, the effects of parasympathetic stimulation on these targets, and the major cholinergic muscarinic (M) receptor subtypes on each target tissue.

- Heart-sinus (SA) node and AV junction (decreased heart rate -- cholinergic M_2)
- Endothelium- (releases EDRF in response to circulating acetylcholine -- cholinergic M_3 which relaxes vascular smooth muscle)

1.2 The Heart

The heart is responsible for pumping blood through the circulatory system. A brief description of the anatomy of the heart and the cardiac cycle are described next.

1.2.1 Cardiac Anatomy

The anatomy of the heart can be conveniently be divided into five functional units:

- The heart muscle (the 2 atria pump blood into the ventricles and the 2 ventricles pump blood out of the heart)
- The valves of the heart which maximize the pumping action of the heart (2 atrioventricular valves: the tricuspid and mitral; 2 semilunar valves: the pulmonic and aortic)
- The electrical pacemaker and conduction system which sets the normal rhythm of the heart and coordinates the contraction of the heart (sinoatrial (SA) node, atrioventricular (AV) junction, His bundle, Purkinje fibers)
- The coronary circulation which distributes blood to the heart itself
- The autonomic nervous system innervation of the heart which regulates heart rate and contractility (sympathetic nerve endings in muscle of atria and ventricles, SA node, and AV junction; parasympathetic nerve endings mainly in atrial muscle, pacemaker, and the AV junction)

1.2.2 The Cardiac Cycle

The proper functioning of the cardiac conduction system, with the consequent coordination of contraction and valve opening and closing in each region of the heart, is critical for efficient pumping of blood. Each phase of the cardiac cycle is described next:

- An impulse arising from the SA node results in depolarization and contraction of the atria (the right atrium contracts slightly before the left atrium)
- The atrioventricular valves open and the ventricles are filled with blood
- There is a short delay of the electrical impulse in the AV junction that allows the ventricles to fill completely
- The electrical impulse is then propagated through the His bundle and Purkinje system to allow the ventricles to contract from the apex of the heart towards the base
- As the ventricles contract and the pressure in the ventricles exceeds that in the atria, the atrioventricular valves close and the atria begin to relax and refill with blood
- When the pressure in the ventricles exceed the pressure in the pulmonary artery and aorta, the pulmonic and aortic valves open, and blood is pumped into the pulmonary and systemic circulations, respectively
- As the ventricles begin to relax after systole, the pulmonic and aortic valves close and diastole begins

1.3 The Vasculature

The vasculature consists of the blood vessels responsible for distributing blood to various tissues of the body.

1.3.1 The Circulatory System

The circulatory system consists of two separate circuits linked in series:

- The pulmonary circulation (low pressure, low resistance). The right heart pumps blood into the pulmonary circulation.
- The systemic circulation (high pressure, high resistance). The left heart pumps blood into the systemic circulation.

1.3.1.1 Blood Vessels

Blood vessels can be classified according to size, location and function:

- Arteries are large diameter, thick-walled vessels that carry blood away from the heart.
- Arterioles are small, thick-walled vessels that represent the major part of vascular resistance. These resistance vessels serve as "circulatory stopcocks" and control the distribution of blood to various organs.
- Capillaries are extremely small, extremely thin-walled vessels (one cell thick) that allow exchange of gases, nutrients, and other small molecules

between the blood stream and tissues. Increases in capillary hydrostatic pressure or capillary permeability can lead to edema.

- Venules are small thin-walled vessels that serve to bring blood back to the heart. These vessels are highly distensible and (along with veins) contain a large fraction of the blood volume.
- Veins are large diameter thin-walled vessels that bring blood back to heart. They are distensible and (in addition to venules) contain a large fraction of the blood volume.

1.3.2 Blood Vessels Controlling Blood Pressure

The major blood vessels controlling blood pressure are referred to as the resistance vessels and the capacitance vessels:

- Resistance vessels. Arterioles are the primary resistance vessels and control mean arterial blood pressure and blood flow to specific tissues. Vascular smooth muscle tone in these vessels is controlled by the sympathetic nervous system and local factors (metabolic need).
- Capacitance vessels. Systemic venules and veins serve as a volume reservoir for the circulatory system (approx. 50% of total blood volume is contained in these vessels). Sympathetic and humoral regulation of these vessels can significantly alter venous return (preload) and fluid exchange in the associated capillary beds.

1.4 Regulation of Blood Pressure

Blood pressure is closely regulated on a short-term (seconds-to-minutes) and long-term (days-to-weeks) basis. Mean arterial pressure is monitored by baroreceptors primarily in the aortic arch and carotid artery and is regulated by two temporally different (but integrated) reflex pathways. Because the response of both reflexes is monitored by the baroreceptors, both reflex pathways are feedback loops.

1.4.1 Short-Term Regulation

Short-term changes in blood pressure (time frame of seconds to minutes) are mediated by the autonomic nervous system. This reflex pathway is described below:

- Changes in mean arterial pressure are sensed by the baroreceptors and processed by the vasomotor centers in the medulla, which differentially regulate sympathetic and parasympathetic nervous system output.
    - If a drop in blood pressure is seen by the baroreceptors, neuronal activity to the vasomotor centers is decreased, resulting in an increase in sympathetic tone and a decrease in parasympathetic (vagal) tone.
    - A rise in mean arterial pressure causes an increase in baroreceptor neuronal activity and gives rise to an increase in vagal tone (activity of the vagus nerve) and a decrease in sympathetic tone.
- Increases in sympathetic tone result in increased peripheral vascular resistance, increased venous tone, increased heart rate, and increased contractility of the myocardium.
- Increases in vagal tone lead to lowering of heart rate.

1.4.2 Long-Term Regulation

Long-term changes in blood pressure (hours to days) are primarily mediated by humoral factors that control blood volume by regulating Na^+ and water retention. The reflex pathways are described below:

- Changes in renal blood flow and pressure, which are directly related to mean arterial pressure, result in changes in renin secretion. A drop in renal blood flow or pressure results in an increase in renin release from the kidney. High sympathetic outflow also causes an increase in renin secretion
- An increase in renin release leads to an increase in circulating angiotensin II. The primary actions of angiotensin II are:
  - To stimulate the synthesis and secretion of aldosterone.
  - To raise blood pressure by direct vasoconstrictor effects (angiotensin II is one of the most potent vasoconstrictors known).
- Aldosterone acts on the kidney to retain Na^+ (and therefore water), leading to an increase in blood volume.

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