Nonlinear dynamic model of baroreceptor blood pressure regulation

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The body's ability to regulate blood pressure through the carotid baroreflex, as well as the reflex's adaptation in hypertensive systems, are explored in this work with special attention to nonlinear properties. Previous model-based studies have produced linear mathematical representations aimed to simulate the body's response to changing arterial blood pressure. These models are limited to the applications of modern linear-feedback control theory, and are successful in analyzing the basics of blood pressure homeostasis. However, they are limited to normotensive pressures and fall short when confronted with pathological extremes in pressure such as for hypo- and hypertensive levels. More recently, studies suggest that nonlinear-control mechanisms should be used. Computer modeling, blood vessel mechanics, and nonlinear-control theory are used to simulate physiological conditions found in normal and hypertensive systems. Using Simulink and a sigmoid function, a dynamic model was created of the carotid sinus' regulatory behavior on blood pressure in response to changing mean arterial blood pressure. One of the main goals was to understand sigmoidal factors that change in hypertension. Results supported that two sigmoid-function parameters (s and μ) affect the pressure and the speed of convergence of the system. It was concluded that a physiologically realistic model of blood pressure regulation is possible once the nonlinear vessel function is incorporated. This new model eliminates the assumptions of the more common linear feedback models, and permits analysis of pathological, hypertensive, conditions.

Keywords— Baroreceptor, Carotid Artery, Hypertension, Nonlinear Dynamics, Simulink

I. INTRODUCTION

The baroreflex is responsible for stabilizing arterial blood pressure via specialized stretch-sensitive baroreceptors, which detect changes in blood pressure in the aortic walls and carotid sinus. The activity of baroreceptor firing rates is dependent on the magnitude and rate of change of blood pressure [6, 7]. Studies on receptor sensitivity to pressure-change have shown that this relationship can be represented by a nonlinear sigmoid function with a minimum threshold pressure and maximum firing frequency saturation [6, 8]. High blood pressure drugs have been developed to help treat hypertension, as well as an implantable device designed to stimulate the carotid sinus to lower blood pressure over time [2–4]. Prior to drug and device treatment of blood pressure, computer model investigation by Guyton resulted in the high salt diet and Kidney theory of hypertension [5]. While this modeling was extensive and included many of the blood pressure regulatory paths, it was limited in its ability to model the true biology. Primarily, this was because it operated within the constraints of linear-control theory. It is hypothesized that a nonlinear blood pressure regulation model will reveal more realistic detail for studying hypertension.

This study is based on the communication between the carotid artery and the brainstem, and exploits how the carotid baroreceptor nerve firing rates change in order to model and understand how this can lead to hypertension.

II. METHODS

Using Simulink, a model was created that uses a sigmoid function as the mathematic model for baroreceptor reflex. Fig. 1 shows the Simulink schematic model used. The two main input signals into the sigmoid function are mean arterial pressure (MAP) and baroreceptor nerve firing rate. The regulating and processing primarily occurs through the sigmoid function and the function's output is compared to a programmed steady state. The model consists of two branches: an upper branch, which was used to simulate the raw data, and a lower branch used to regulate the system. This lower branch can represent a potential device regulation mechanism or the cardiovascular-neural center of the brain.

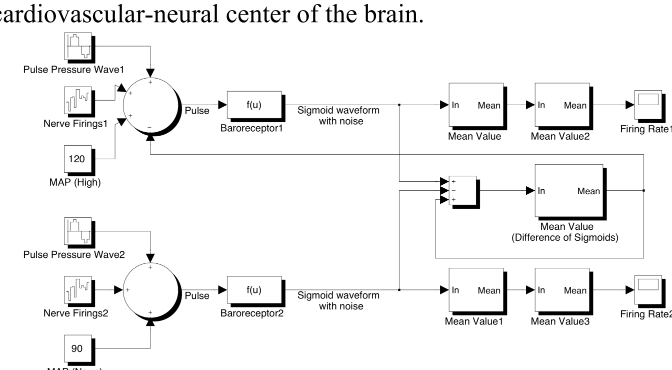

Fig. 1: Schematic of nonlinear dynamic model of baroreceptor blood pressure regulation (shown for hypertensive simulation).

Based on a previous study by Drzewiecki, a sigmoid function of the basic form (1) was used to represent the basic Carotid artery mechanical function for the model [9].

$$f(x) = \frac{\alpha}{1 + e^{\frac{\mu - x}{s}}} \quad (1)$$