Abstract. The Matsuoka neural oscillator can potentially be employed as the central pattern generator (CPG) for a chewing robot, in order to generate and adapt rhythmic actuations in response to sensory feedback. In this chapter a single Matsuoka oscillator of two neurons is applied to two phase-locked muscles (e.g. masseter and digastric muscles) or for a single robotic joint. Three graphical user interfaces (GUIs) were developed to help design and tune the oscillator. A case study is presented involving a jaw, driven by a couple of opening and closing muscles and commanded by motoneurons. The force of the muscles was described using a nonlinear Hill model while the motoneuron for muscle activities was modelled using the oscillator. Simulations were performed to show the oscillator’s ability to generate and adapt its rhythmic outputs with respect to chewing without food (i.e. EMG only for rhythmic muscle activities), with foods (i.e. EMG for rhythmic and additional muscle activities) and with crushable foods (to see how quickly the oscillator to reduce its force commands in order not to damage the teeth). Furthermore, a hardware-in-the-loop simulation system is presented to validate this neural controlling algorithm, where the chewing robot is actuated by two fluidic muscles commanded by the Matsuoka oscillator. The robot had a fixed upper jaw and actuated lower jaw, with position and force sensors used to measure jaw movements and the food resistance. The oscillator, simulated in Matlab, was interfaced to the control valves of the fluidic muscles via a sensory I/O card. The control of the robot is achieved via Simulink with the real-time windows library. Comprehensive experiments were conducted and the results interpreted to show the distinct dynamic behaviours of the neural controlling algorithm.

9.1 Why CPG for Control

Human mastication patterns vary between subjects and with food texture and are continually modified throughout the chewing sequence in response to the food dynamics. This interactive relationship has been utilized to evaluate textural

properties of foods by measurement of masticatory physiology [1, 2]. The challenge in evaluating foods this way is that mastication is difficult to fully characterise and to some extent, the measurements themselves interfere with the natural chewing behaviour. As result, food texture can only be evaluated semi-quantitatively and various hypotheses could not be tested on human subjects easily.

To this end, a chewing robot solution has been proposed [3, 4]. The idea is that while being chewed by a robot, the food properties and textural changes occurring during chewing are evaluated by robotic actuations states, chewing force, and/or jaw movements. Although it could be used to chew foods, the WJ (Waseda Jaw) robot series were developed to work especially with the WY series dental training robots [5, 6]. They did not take into account the biological aspects of the human masticatory system and hence the robotic states can’t be used for purpose of food evaluation. The 6RSS mechanism parallel chewing robot reported in Chapters 3 and 4 [7, 8] was based on biomechanical specifications derived from the jaw structure and the muscles of mastication. It was developed especially for food evaluation. These robots may be commanded to chew foods by following recorded masticatory movements and chewing forces, but do not mimic the variations in trajectory and force application in response to the changing food properties in the way a human does.

The chewing of foods by humans is performed by the movement of the jaw due to the muscles of mastication. Alpha-motoneurons (or alpha-MN) innervate a muscle by recruiting a number of motor units and firing them at various frequencies [9, 10]. Electromyography (EMG) measurements have confirmed that a small amount of muscle activity is required for the free rhythmic movements of the jaw, and are produced by the central pattern generator (CPG). Additional voluntary muscle activities are generated in the alpha-MN’s if the closing movement is resisted by foods [11, 12]. The harder the food, the larger the muscle activity required [13, 14].

In principal, the muscles of mastication involve anticipatory (or feed-forward) activities for pre-programmed movement depending on individual chewing expectations, rhythmic activities generated by the CPG that are dictated by individual physiology, and voluntary (sensory feedback) activities for overcoming food resistance. To make a chewing robot chew in a human way, these rhythmic, anticipatory and voluntary patterns of muscle activity should be implemented.

A CPG can produce coordinated rhythmic muscle activities without any sensory input. CPG’s have been modelled as systems of neural oscillators, such as the Ellias-Grossberg oscillator [15], Matsuoka oscillator [16], RIO [17] and van der Pol oscillator [18]. These CPG models can not only generate robust, the sustained oscillations necessary for many human body movements (such as chewing, locomotion, heart beats and breathing), but can also be modulated to induce gait transition or variations smoothly [19]. Matsuoka oscillator based CPG models have been popular for humanoid control of robots, such as robotic armed and legged devices [20, 21], where the dynamics of the robots are exploited to entrain the oscillators.