Chapter 3

Research Framework

3.1 Introduction

In this chapter, the research framework is proposed (Section 3.2) in terms of how to tackle an excavator digging process. This description is critical to understand the development of the mathematical model of excavator digging in Chapter 5. The knowledge is general enough to be applied to any cases of excavator tool-soil interaction.

This is followed by the description of how this research framework can be realized in the development of a VR excavator simulator system by proposing its essential components along with their roles, as well as calculation and data flow in the system (Section 3.3). A more complete description is presented in Chapter 6. Even though this description is specific to the VR simulator development for a construction excavator, the general scheme can be applied to different types of excavating machines for their own VR simulators.

3.2 Framework for Analyzing Excavator Digging Process

The framework starts from the idea that a digging process of an excavator can be segmented into pieces and each segmental piece represents a snapshot of a digging action at that point in time. Depending upon the number of segments, there could be numerous corresponding digging actions. However, these digging actions can be classified into a few common groups, each of which represents an unique bucket-induced soil resistance calculation scheme. Thus no matter how many segments exist within a digging process, they somehow belong to particular digging action groups. Therefore, identified digging action groups are used as building blocks to form a certain digging process (These digging action groups will be referred to as *digging modes* hereinafter). Differently put from the perspective of machine operation, when an excavator driver operates an excavating bucket to dig soil, his/ her continuous operation is divided into a series of discrete steps of operation, which eventually matches to a series of corresponding digging action groups or digging modes. This is graphically depicted in Figure 3.1. In the figure, the combination of bucket penetrability/ separability and motional versatility attributes to various digging modes. In other words, the more combinations are made out of machine's penetrability/ separability/ versatility, the larger the number of digging modes are conceived. As an extreme case, consider a dozer-type excavating machine. These machines break soil by separating it in a linear movement fashion. Thus no matter how many segments are made in an excavating process, there is only one digging mode existing in this type of machines. A description of digging modes of a construction excavator is detailed in Chapter 5 and Chapter 6.

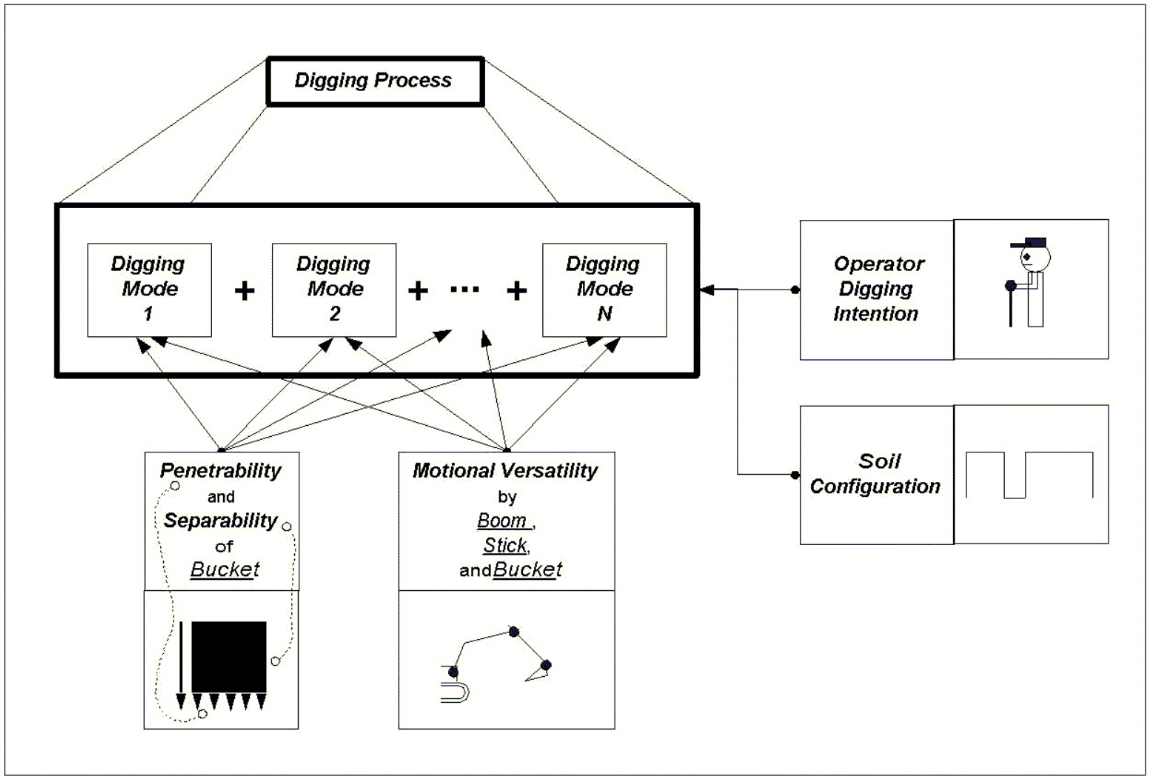

Figure 3.1 Research Framework for the Analysis of Excavator Digging Process

Note that in the figure operator digging intention and soil configuration are introduced as factors that change digging mode from one type to the other, eventually leading to the discussion how to select a digging mode for a certain digging action.

3.3 Architecture and Calculation Flow of a VR Excavator Simulator System

The general architecture and calculation pipeline of a VR simulator presented in Chapter 2 are refined in this section specifically for an excavator machine type in terms of how they serve the development of the system as shown in Figure 3.2. The following describes what the essential components are in a VR excavator simulator; what actions need to be taken in each component; and how and what calculation information are transferred from one component to another. A more detailed description on how the calculation is performed in each data level follows in Chapter 6.

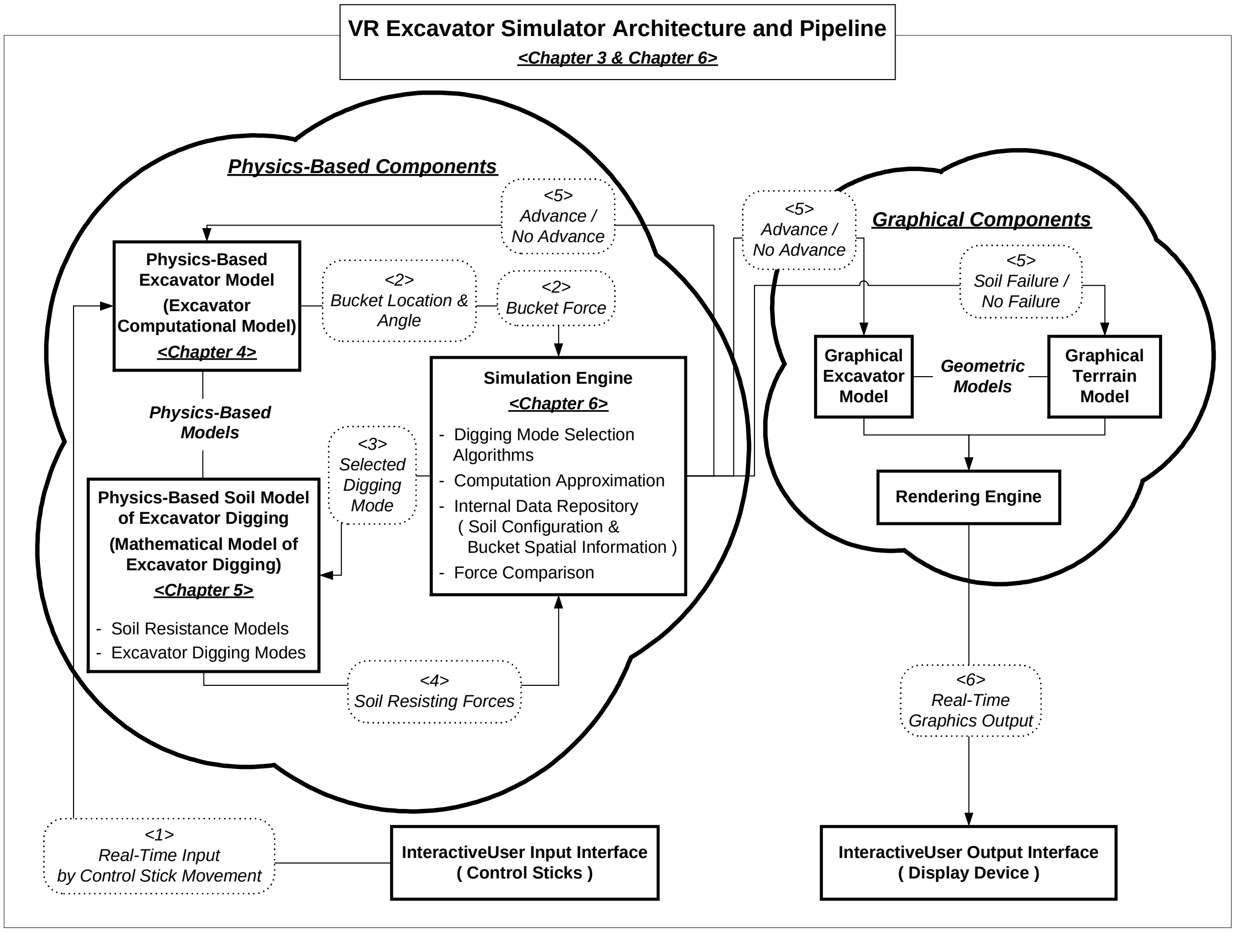

Figure 3.2 Architecture and Pipeline for a VR Excavator Simulator

The whole calculation process gets initiated by a simulator operator, who prompts an interactive user input interface, i.e., excavator control levers, to provide real-time input signals for a physics-based excavator model. These signals basically convey information as to which hydraulic valve or valves should be actuated by how much, and eventually control the movement of corresponding parts such as a bucket, a stick , a boom and an upper body. Even though these inputs are transmitted continuously in the form of analog signals, they are handled as if they were a string of segmental signals after being converted to digital signals. The time length of one input segment is determined by the performance of the system.

Upon receiving one input segmental signal, the physics-based excavator model (or excavator computational model) calculates a static force of the bucket tool (or a bucket breaking force) generated from the relevant hydraulic cylinder displacements for this time interval. The description of force calculation is presented in Chapter 4. This force information is stored into a simulation engine for further evaluation with soil resistance. Note that since the velocity of a bucket in a soil medium is usually very low except at the moment of its first inception into soil, it is assumed that the dynamic force can be neglected.

The physics-based excavator model (or excavator computational model) also produces spatially and temporally valid behavior of a bucket such as its location and its inclined angle at the current segmental time (Chapter 4). At this point, given the bucket in the soil medium, the bucket spatial information is just tentative because it is not yet certain that the movement is physically possible without considering a response (resisting force) from soil and the bucket breaking force together. This information, however, is very crucial in the sense that the bucket's movement has initiated resistance from soil. Thus this spatial information is transferred to the simulation engine to generate proper soil resistance from a physics-based soil model of excavator digging (or mathematical model of excavator digging).

The simulation engine then matches the current digging operation to a certain digging action group or digging mode from the bucket spatial information saved for the current and the previous time steps as well as from the current control lever operation (Section 6.3). The simulation engine additionally checks the data repository or data structure to refine the bucket spatial information into the one relative to soil configuration. The selected digging mode and soil-configuration-relative bucket spatial information is passed to a physics-based soil model of excavator digging (or mathematical model of excavator digging).

The physics-based soil model of excavator digging (or mathematical model of excavator digging) functions as the source of proper reactions to the current bucket movement calculated from the physics-based excavator model by calculating soil resistance forces based upon the identified digging mode from the simulation engine. Each of digging modes represents an unique resistance calculation scheme (Chapter 5).

Once a resisting force is calculated, it is sent back to the simulation engine so that it can be compared with the bucket breaking force. The comparison provides the basis that the portion of soil has been failed or not during the current time interval. If the soil is calculated to fail, the simulation engine notifies to the physics-based excavator model that the currently tentative displacement of the bucket is physically valid and the proposed bucket location and angle are updated. This triggers the internal data repository to update itself to provide appropriate information for the next calculation step. Simultaneously, the simulation engine makes the graphical components updated for the geometric representations of an excavator and a terrain. These geometric excavator and terrain models get rendered real-time on a display device. And this process repeats for the next segment input signal.

However, if the soil resistance were bigger than the bucket static force, i.e., the indication of no soil failure, the simulation engine nullifies the tentatively calculated information corresponding to the current time segment. And it signals the physics-based excavator model to correct its state back to the point where the current calculation began.

3.4 Conclusion

The suggested framework of a digging process provides an analytical basis, by which even the most complex soil-tool interaction between an excavator and soil is analyzed effectively. The main idea of the framework is that any digging process of an excavating machine is segmented into pieces, and each of the segmental pieces belongs to a certain digging action group (or digging mode) in terms of its associated soil resistance calculation scheme.

Based on the proposed framework and the general VR simulator descriptions presented in Chapter 2, the architecture and the calculation pipeline of a VR excavator machine simulator system are identified in terms of system components, their roles, and their interactions with other components along with the data and the information transferred between these components.

The framework and the VR excavator simulator architecture presented in this chapter are the starting points of the discussions and the developments in the following chapters (Chapter 4, 5, and 6).