Haptic Pulse Simulation for Virtual Palpation

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Abstract. In this paper we propose a software-based approach to simulate the haptics of the human pulse. This effect can then be interactively explored by virtual palpation. The algorithm features a flexible, user-defined setup. In addition the simulation takes dynamic parameters into account and allows for many different use cases.

1 Introduction

The pulse is one of the most essential sources of information for medical diagnosis. It is primarily used for measuring blood pressure or monitoring the circulatory system. In addition, the pulse is a palpable landmark that allows to determine the position of arteries. This knowledge is regularly applied to locate insertion sites for needle penetration in regional anaesthesia. Until now, there is no software-based trainer that simulates this effect for palpation procedure.

Two selected examples are a mechanical-based skill trainer that simulates the pulse with pneumatic tubes in a corpse [1] and a software-based endoscopic simulator, that visualizes hemodynamics without haptics [2]. Instead of these, our focus lies on the haptic simulation of a pulse. Also, our goal is to provide feasible results in real-time and not create an accurate bloodflow simulation.

Our approach is a flexible software-based haptic simulation of the pulse. This allows for different scenarios (i.e., patient data-sets and various body regions) and is also meant to be used as a component in other simulators (e.g., [3]).

2 Materials and Methods

Because the pulse can be only detected in specific areas of the human body we propose a local simulation scheme. First we give a description of the setup and algorithm. Afterwards, the different components are explained in more detail.

2.1 Model and Setup

To model a pulse region we construct it out of one or multiple particles. These particles are then defined as emitting sources for the local pulse (cp. Fig. 1). Usually, the particles reside within an artery and are close to a prominent surface point where the pulse can be palpated. Some typical regions are: carotid pulse (located in the neck), brachial pulse (between biceps and triceps, femoral pulse (located at the thigh), etc. Thus one can define multiple regions.

Then we setup a virtual proxy that is coupled to a haptic input device for palpation [4]. The proxy is used for collision detection and contains, the position and orientation of the tooltip of the device.

2.2 Algorithm of Pulse Simulation

Our algorithm is divided into a two-phase collision detection and the actual simulation:

1) broad phase

```
for all pulse_regions do
  cd_pair = collision_detection(region, proxy)
  if (cd_pair) then narrow_test(cd_pair)
```

2) narrow phase

```
for all pulse_particles of region do
  cd_pair = collision_detection(particle, proxy)
  if (cd_pair) then pulse_simulation
```

3) pulse simulation

```
magnitude = calculate_pulsewave(t, parameters)
force = project(magnitude, distance, collision normal)
send_to_hapticrenderloop(force)
```

2.3 Properties of Pulse Simulation

The particles that define a pulse region contain several specific configurable parameters.

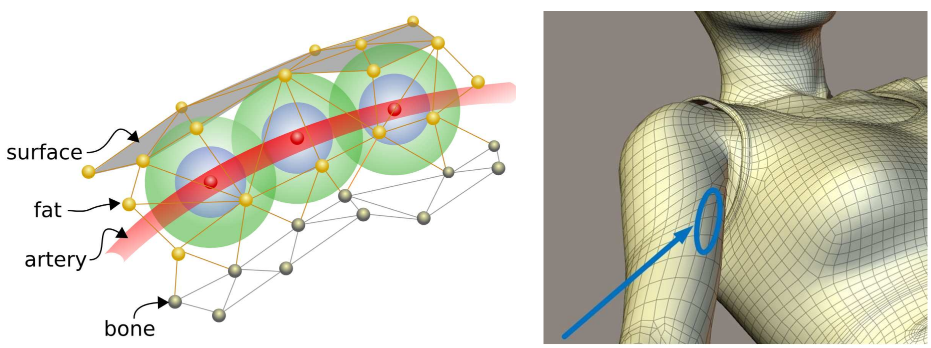

Fig. 1. Setup of several pulse particles to model a pulse region (here: brachial pulse)

- *Pulse range*: One set of parameters that is associated with a particle describes the effective *pulse range*. This determines the space or radial extent relative to the point of the particle's position (cf. Fig. 2) and allows to use a fast point-to-sphere collision detection scheme. If the haptic probe interferes this proximity range, a pulsating force feedback is rendered. Depending on the layer or distance the intensity of the force can be attenuated.
- *Pulse wave*: The human *pulse wave* can have different shapes depending on the current constitution of the patient and on the pulse region. As a first approximation we use the rectangular waveform model. It consists of the pulse's *duty cycle* (D) as the ratio between the pulse *duration* (τ) with the wave *amplitude* and the *period* (T). According to findings from psychophysics this approximation should be sufficient in most cases, because of the just noticable difference in human haptics perception [5] and the limited resolution of the haptics devices. In case a more accurate model is needed, the algorithm supports the use of lookup tables that can be sampled from the readout of medical sensory instruments [6].
- *Pulse rate*: The *pulse rate* of a normal human ranges from 60 to 100 beats per minute (BPM), although this can vary depending on different circumstances (e.g., sports etc.). This corresponds to the length of the pulse period T. In the simulation it can be varied during runtime.

2.4 Haptic Rendering

For the haptic rendering a force and a direction must be computed. The direction is defined by the vector that connects the particle position with the collision point of the particle's sphere with the haptic probe. The force is proportional to the

Fig. 2. Two-layered pulse range and desktop setup of the haptic palpation

current pulse wave reading. It can be relatively adjusted to the devices output range. To achieve a consistent pulse frequency (BPM), rendering is maintained by using a haptic timestamp. The timestamp is used to verify delays in the control information of the haptic media. The output of the pulse period is then adjusted as a function of the haptic rate. The haptic surface rendering is done by the virtual proxy as described in section 2.1.

3 Results

As an example we describe the use case of searching for a pulse landmark. A virtual patient is visualized on a VR desktop system. The haptic device is controlled by one or multiple fingers of the user and the current position and orientation is displayed by a virtual hand (cf. Fig. 2). This allows the user to explore the skin surface intuitively in real-time. As soon as the haptic proxy reaches within the effective range of a pulse particle a pulsating effect can be haptically perceived. Depending on the region and penetration depth, the feedback ranges from faint to strong. Furthermore, preliminary evaluations have shown that usually one to three pulse particles are sufficient to represent a pulse region.

4 Discussion

As described by the example in the results, the simulation allows for an intuitive exploration of the human pulse. Through the usage of particles with bounding spheres the collision detection works efficiently. It is very flexible due to the many parameters and the support of lookup tables for different pulse wave forms. In summary, the haptic pulse simulation algorithm contributes to virtual palpation and enables dynamic, pulsating landmarks in real-time. Purely mechanical solutions are more specialized and realistic, but they are also less flexible. In our scenario we emphasize on reusability. Hence, effortless changes are essential. This is covered by our software-based approach and further supported by the individual setup.

Future work could focus on fine tuning the parameters and adding more realism. The collision detection could be extended to support a deformable skin. The parameters can be modified by medical experts and will be evaluated in a user study.

Acknowledgement. This work was funded by a grant from the German Research Foundation (DFG, KU 1132, LE 1108, RO 2000) and also supported by the START program (UK Aachen).

References

1. Schwarz G, Feigl G, Kleinert R, et al. Pneumatic pulse simulation for teaching peripheral plexus blocks in cadavers. Anesth Analg. 2002;95:1822–3.

2. Cakmak H, Kuhnapfel U. Animation and simulation techniques for vrtraining systems in endoscopic surgery. In: Eurographics Workshop on Animation and Simulation; 2000. p. 173–85.
3. Ullrich S, Fischer B, Ntouba A, et al. Subject-based regional anaesthesia simulator combining image processing and virtual reality. Proc BVM. 2007; p. 202–6.
4. Ruspini D, Khatib O. Dynamic models for haptic rendering systems. In: Advances in Robot Kinematics: ARK'98; 1998. p. 523–32.
5. Allin S, Matsuoka Y, Klatzky R. Measuring just noticeable differences for haptic force feedback: A tool for rehabilitation. In: Proc 10th IEEE Symposium on Haptic Interfaces for Virtual and Teleoperator Systems; 2002. p. 299–302.
6. Hlimonenko I, Meigas K, Vahisalu R. Waveform analysis of peripheral pulse wave detected in the fingertip waveform analysis of peripheral pulse wave detected in the fingertip with photoplethysmograph. Measurement Science Review. 2003;3(2):49–52.