

Towards the third generation of surgical simulators

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Minimally invasive surgery (MIS) gets more and more common nowadays. A minimally invasive surgery is one that is less invasive than the open surgery used for the same operation. A minimally invasive procedure typically involves use of laparoscopic devices and remote control manipulation of instruments with indirect observation of the surgical field through an endoscope or similar devices. They are carried out through the skin or through a body cavity or anatomical opening. This may result in less pain, less strain of the organism, small injuries (aesthetic reasons), economic gain because of shorter hospital stays, or even allow outpatient treatment. On the other hand, there exist some important disadvantages for the surgeon as restricted vision of the surgeon, difficult handling of the instruments, very restricted mobility, difficult hand-eye coordination and no tactile perception. Therefore, an important training phase is required before a surgeon acquires the skills necessary to adequately perform minimally invasive surgery.

Model order reduction techniques (MOR) have shown to constitute a valuable tool for real-time simulation in surgical training environments and other fields. However, some limitations, imposed by real-time constraints, have not yet been overcome. One of such limitations is the severe limitation in time (established in 500 Hz of frequency for the resolution) that precludes the employ of Newton-like schemes. Thus, reduced models in real-time environments are actually linear, although the best set of basis functions, in statistical sense, is employed.

In this work we present a technique able to deal with geometrical and material non-linearities, based on the employ of model reduction techniques, together with an Asymptotic Numerical Method (ANM) to expand the solution in the neighborhood of the last equilibrium point. This constitutes, up to our knowledge, the first prototype of surgical simulator of the second generation (i.e., that in which not only anatomy, but also accurate constitutive equations are solved and represented in real time).

Then we have combined model order reduction technique (MOR) and extended finite element (XFEM) for the interactive simulation of the surgical cuts such as being practiced in surgical treatment. Some examples of the performance of the technique over academic as well as surgical examples will be given.

The employ of model reduction techniques in a multiscale framework will open the possibility to reproduce accurately the anatomy, the tissue behaviour and also physiology (blood flow, breathing, ...). With this, the third generation of surgical simulators is now at hand.