Chapter 6
Visual Servoing for Beating Heart Surgery

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Abstract. Off-pump coronary artery bypass grafting (CABG) is still a technically challenging procedure. The existing mechanical stabilizers used for local suppression of the heart excursion have demonstrated significant residual motion, which could lead to a lack of accuracy in the surgical task, particularly in a minimally invasive surgery (MIS) context. Robots can help the surgeon by actively compensating for the heart motion using visual servoing. Various sensors like endoscopic camera, ultrasound imaging or even magnetic resonance imaging (MRI) can be used to provide the feedback of the visual loop. Advanced control approaches like predictive, repetitive or robust control can enhance the compensation accuracy. They rely on a model that uses physiological inputs to predict the motion of the myocardium in real-time.

6.1 Introduction

For many patients, CABG is still the only solution for myocardium revascularization. CABG is one of the most common surgical intervention in Europe and especially in North America. According to the organization for economic cooperation and development (OECD) 2008 health database [33], 12 European countries reported in 2006 an average of approximately 50 CABG procedures per 100,000 in-patient population. In 2004, the United States reported 145 procedures per 100,000 in-patient population. So, improving the quality of this intervention by

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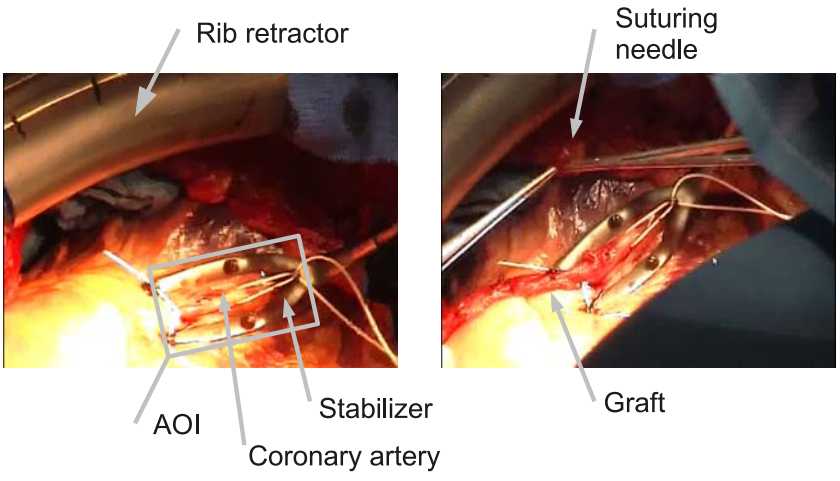

Fig. 6.1 Conventional off-pump CABG procedure

reducing complications, patient pain, hospital stay and recovery time would yield a major societal impact.

In a conventional CABG, access to the heart is obtained by a large cut in the chest along the sternum (sternotomy). The two parts of the rib cage are maintained thanks to a retractor (see Figure 6.1). When operating on a beating heart (off-pump), a mechanical stabilizer helps reducing the motion of the myocardium locally. The graft, previously harvested, is used to shunt the stenosed (abnormally narrowed) coronary artery. Connecting one side of the graft to the coronary artery requires many sutures: this connection is called the anastomosis.

One of the main way of improvement for CABG is minimally invasiveness. Using a minimally invasive access to the heart through tiny holes in the chest prevents from the complications due to sternotomy, reduces patient pain, hospital stay and recovery time. CABG performed this way is usually called totally endoscopic coronary artery bypass (TECAB). The other important improvement is beating heart surgery. Letting the heart beat during CABG or TECAB prevents from some serious complications, mainly neurological ones [8, 43]. This is now routinely performed in open-surgery but is still challenging in a minimally invasive context. The robot is a promising tool to help this kind of surgery. Thanks to telemanipulated endoscopic tools with internal mobilities and stereo visual feedback, the surgeon can achieve the grafting even on a moving organ. However, to reduce the motion of the area of interest (AOI) (approximately 1 cm^2 around the grafting area), surgeons have to use a heart stabilizer. It constrains mechanically and passively the relative motion between the AOI and the operation table. Despite this stabilization, the residual motion of the AOI is still significant [27] and surgeons cannot use the same techniques for TECAB than for open CABG, especially when suturing [18]. These workarounds to cope with residual motion have drawbacks and limitations [21].