Computers and Electrical Engineering 000 (2017) 1–16

Contents lists available at ScienceDirect

Computers and Electrical Engineering

journal homepage: www.elsevier.com/locate/compeleceng

# Evaluation of a new virtual reality micro-robotic cell injection training system☆

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ARTICLE INFO

*Article history:*
Received 7 May 2016
Revised 25 April 2017
Accepted 25 April 2017
Available online xxx

*Keywords:*
Micro-robotics
Haptic interfaces
Virtual reality
Performance evaluation
Skill training
Cell injection

ABSTRACT

This study considers a virtual reality (VR) micro-robotic cell injection training system developed to reduce the time and cost required for a trainee to become proficient in cell injection. The VR environment replicates a micro-robotic cell injection setup to be interacted with and controlled using either a keyboard or haptic device. Using these two input control methods, user training evaluation experiments were designed and conducted to evaluate trainee performance. The performance improvement of 13 participants after undergoing training was analyzed. Results demonstrate that the participants attained higher accuracy and success rates when utilizing the haptic device control method than when applying the keyboard control method. All participants successfully performed the required task when employing the haptic device control method with haptic guidance enabled.


## 1. Introduction

Cell injection is a procedure in which a small amount of material, such as protein, DNA, sperm, or bio-molecules, is injected into a biological cell. Since the introduction of enabling technology early last century, cell injection technology has been widely applied to many areas. For example, in intracytoplasmic sperm injection, cell injection technology is used for injecting an immobilized sperm into the center of a mature egg to stimulate fertilization. Another widespread cell injection application is in drug development where researchers inject drugs into a cell and observe the effects.

Micro-robotic cell injection is typically performed by an expert human bio-operator with extensive training and experience. The procedure involves delicate operations, such as positioning the micropipette accurately to penetrate the cell membrane and inject the foreign material appropriately. Successful cell injection procedure requires a high skill level.

Despite utilizing micro-robots capable of high precision movement, successful injection is often inaccurately reproducible, thus contributing to high failure rates even among experienced bio-operators [1]. The micro-robot movement is controlled manually through which a bio-operator uses input controllers, such as rotary encoders or a joystick for each of the *x*, *y*, and *z* axes. This human-in-the-loop approach remains common practice because human-level judgment and intuition, adaptability, and flexibility are crucial during cell injection [2]. However, it presents several major drawbacks in terms of speed,

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Associate Editor Dr. A. Chaudhary.
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http://dx.doi.org/10.1016/j.compeleceng.2017.04.030
0045-7906/

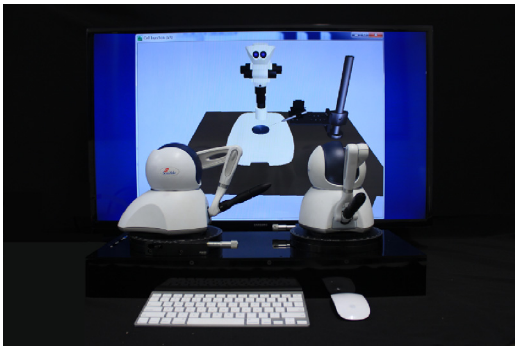

**Fig. 1.** Haptic VR training environment for micro-robotic cell injection and reconfigurable haptic interface [9,10].

precision, throughput, and reproducibility [3,4]. Suitable human–machine interfacing should also be considered to optimize this approach [5].

Several requirements must be considered in biological manipulation such as cell injection. The cell as the manipulated object and micropipettes as tools are extremely small, and the associated contact force is within the mN to µN range [6]. Therefore, different skills, such as precise positioning, puncturing, and penetrating, are crucial. Injection accuracy, trajectory, speed, and force are also significant in successful injection [1,7].

VR is an area that has received much interest among researchers for its capability to provide effective learning and practice environment. Most VR training systems present advantages over real-life training in terms of cost, portability, and flexibility. Haptic technology has also played a significant assisting role in motor skill training since its introduction two decades ago. Significant growth is currently observed in the haptically enabled VR systems development, which is designed to efficiently train humans for various physical tasks. Haptically enabled VR systems have been employed in many skill training applications, such as gunnery, sports, surgery, and art. Utilizing haptics and VR offer significant benefits in skill training. This study introduces a haptically enabled VR environment developed specifically for micro-robotic cell injection skill training.

The proposed haptically enabled VR micro-robotic cell injection training system provides bio-operators with immersive virtual environment. Aside from the interactive virtual environment of a micro-robotic cell injection setup, the system provides haptic feedback to bio-operators as guidance and for increased immersion sense. A detailed discussion of the system is presented in Section 2. An experimental evaluation was designed and conducted to validate the usability and effectiveness of the system using a group of participants. The design of the experimental evaluation is discussed in Section 3. The analysis and discussion of the experimental evaluation are then presented in Sections 4 and 5, respectively. Finally, the conclusions and future works are drawn and suggested in Section 6.

## 2. VR micro-robotic cell injection system

The VR micro-robotic cell injection training system extends our previous work, which discusses keyboard control for cell injection [8], to also consider haptic input control and feedback from virtual fixtures (VFs) [9].

The virtual micro-robotic cell injection environment also utilizes the reconfigurable haptic interface (Fig. 1) from our prior work [10]. The haptic interface can be employed with up to two Phantom Omni (now known as Geomagic Touch) haptic devices for various application types. This system also comprises a computer and power supply attached inside the base compartment for portability.

### *2.1. System development*

A low-cost, portable, and flexible VR micro-robotic cell injection training system [11] is proposed in this section. The training system employs haptic interaction to provide force-based guidance and learning assistance according to different metrics. The waterfall model [12] was utilized to develop the VR training system. This model is a conventional software development model with five sequential stages, and each stage must be completed before the next stage can be executed (see Fig. 2). The literature suggests that the waterfall model is best suited for small project development in which requirements are explicitly recognized [13]. This scenario applies to the development of the VR micro-robotic cell injection training system in which requirements are clearly defined to assist the bio-operator in improving their cell injection skills. These skill requirements are a performance function against identified metrics, such as injection trajectory, force, and accuracy. This section presents the development of the VR system focusing on the first three stages of the waterfall software development model (i.e., requirement, design, and implementation). The verification and maintenance stages are discussed in Sections 4 and 6, respectively.

Please cite this article as: S. Faroque et al., Evaluation of a new virtual reality micro-robotic cell injection training system, Computers and Electrical Engineering (2017), http://dx.doi.org/10.1016/j.compeleceng.2017.04.030