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Workcell for Hybrid Medical Device Fabrication

Nicholas Ho[a,*], Wilson Ang[a], Chee-Kong Chui[a,b]

[a] *Department of Mechanical Engineering, National University of Singapore, 9 Engineering Drive 1, Singapore 117576, Singapore*
[b] *Advanced Manufacturing Research Institute, National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan*

* Corresponding author. Tel.: +65-9621-9043. *E-mail address:* e0013180@u.nus.edu

Abstract

Optimizing assembly is an important process for fabrication of hybrid medical devices comprising multiple components and materials. The process is highly complex, time-consuming and requires the devices to be free from contamination. It requires highly skilled and well-trained workers and a sterile and conducive environment to perform the assembly operations. However, the assembly of medical devices is often neglected and/or overlooked. We propose a novel, intelligent workcell system design that aims to effectively guide operators in the assembly process while maintaining the necessary environmental settings. The potential of the proposed workcell for fabrication of an artificial trachea is investigated.

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Keywords: Hybrid medical device; fabrication; assembly workcell; human-AI collaboration

1. Introduction

The fabrication of hybrid medical devices involves multiple components and materials, both synthetic and biological (e.g. nanotubes, polymers, stem cells, deoxyribonucleic acid) [1, 2, 3]. Most of the past research on this topic have explored and worked on, for example, bioreactor designs, material combinations, scaffold fabrication methods, and improving biocompatibility and/or mechanical integrity of scaffolds [3, 4, 5]. However, assembly, being an important part of any fabrication process, is often neglected and/or overlooked in hybrid medical device fabrication processes. Research has shown that generally, productivity can increase significantly by improving the assembly process [6, 7, 8]. And because hybrid medical devices require a series of material combinations, cell seeding/culturing, and have to be patient specific, the assembly of hybrid medical devices is considered to be a highly complex and time-consuming process, and the working environment has to be free from contamination during the process [9].

The assembly of hybrid medical devices is dependent on two main factors: (a) highly skilled and well-trained workers and (b) a sterile and conducive environment [9]. These dependencies, however, pose many underlying issues such as high costs and time incurred to hire/train highly skilled workers [10], and high costs and energy consumption required to maintain a cleanroom environment [11], which cannot be ignored in a commercial manufacturing industry. Although physical robot aids are commonly used to reduce over-reliance on human skills and abilities [12], they may not be feasible in this application because of the complexity in the assembly process, thus questioning the feasibility of Human-Robot Collaboration (HRC) and fully automated based assembly for such application types, and concluding that manual based assembly is the most suitable for such complex tasks with relatively low volume [13]. Moreover, high initial capital investment is required for any customized robotics setup which in such cases is not justifiable as hybrid medical devices are not considered to be high value and high volume products, as compared to other products like automobiles [14]. Hence, in order to solve the above mentioned underlying issues, an alternative assembly aid cum environment control system has to be introduced.

In this paper, we proposed a novel workcell system design that aims to effectively guide operators in the assembly process while maintaining the necessary environmental settings. Besides increasing fabrication productivity, the Intelligent

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Workcell system design will not only tremendously reduce the learning curve and required skill level of the operator via its **unique AI assistance platform**, but it will also promote sustainability via its **dynamic environment control capabilities**.

2. The Intelligent Workcell Architecture

Referring to Fig. 1 and Fig. 2, the intelligent workcell architecture consists of two main systems: (a) *Real-time AI Assistance System* (RAAS), and (b) *Dynamic Environment Control System* (DECS).

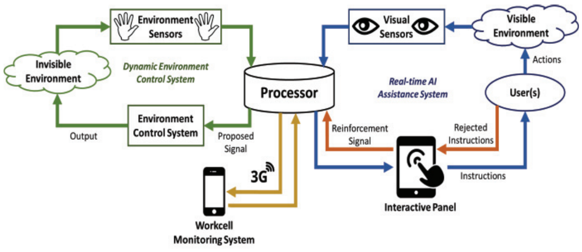

Fig. 1: The Intelligent Workcell Architecture

Fig. 2: Visual Illustration of the Proposed Intelligent Assembly Workcell

2.1. Real-time AI Assistance System (RAAS)

The RAAS is a human-AI collaboration system whereby the human interacts with the AI, and vice versa [15] to carry out complex assembly operations; the AI will provide real-time guidance and the operator will manually conduct the assembly tasks based on the AI's instructions.

When assembly operations begin, the RAAS will be activated and the processor (the "brain" of the AI) will propose the first assembly step to the user via the interactive panel, which will alert the user and display the step using sound and animation aids respectively. At this stage, the user can choose to acknowledge the proposed step by performing the recommended action(s). However, the AI can also "learn" from the operator if he decides to reject the given instructions from the AI via the interactive panel at any given assembly step, and carries out his own step action(s). The visual sensors, being the "eyes" of the AI, will detect any visual activities in the workcell. The collected visual data will then be sent to the processor, where the data will be broken down to match and identify the relevant assembly step. If the step is incorrectly executed, the AI will alert the user via the interactive panel and the user has to correct the step action(s). However, if the step is correctly executed, the processor will propose the next assembly step to the user and this cyclical process will continue until the entire assembly task is completed. The RAAS cyclical process can be summarized in the flowchart in Fig. 3.

In order to prove the feasibility of the proposed RAAS concept, we have identified existing and/or proven technologies/equipment that can be easily integrated in the system. Firstly for the processor, as it requires a certain level of artificial intelligence to actively perform decision-making tasks (e.g. proposing assembly step, processing visual data to match and identify if the relevant step is correctly executed, control environment settings via DECS) and to interact with the user [16, 17], AI programming is essential in the processor design. Reinforcement learning and neural networks can be integrated in the AI programme to ensure its abilities to learn from the user actions and to enhance its capabilities respectively [18, 19]. Machine vision technology can also be integrated in the AI programme to allow the AI to recognize various patterns, objects and faces even at various orientations and/or distances, and to aid in the inspections of sub-assemblies and/or cell growth progress [20, 21]; sensor fusion and background filtering can be utilized to improve the machine vision capabilities of the AI [22, 23]. Lastly, as the processor is required to store various forms of data (e.g. the AI programme, the predefined assembly steps, learnt step actions, sound and animation files to guide the user), a knowledge database has to be considered as part of the processor design [24].

Secondly, the interactive panel acts as a communication bridge between the AI and the user. Hence, it requires tools that allow the AI and the user to actively interact with each other. Inspired by current popular culture trends to own a smart device, we propose an interactive panel platform to have similar features like the touch technology, sound/voice response and recognition, and display panel [25]. As the current generations are already comfortable with this technology, we believe that this platform is the most effective way to promote effective human-AI collaboration.

Lastly, the visual sensors act as a real-time, visual detection platform for the AI by capturing any visual activities in the workcell before the visual data can be processed in the processor [26]. Cameras in various types (e.g. stereo, time-of-flight (ToF)) and/or quantities can be used concurrently to perform this task effectively and efficiently [27]; this method is most commonly used in machine vision inspection on products [28], and recently on human-robot collaboration applications to achieve better visual detection coverage in the workcell to avoid collision and eliminate redundant movements [29]. The activities detected by the visual sensors also have an influence on the DECS via the processor. The processor and the visual sensors are key sub-systems that aid in the DECS; this will be further elaborated in the next section.

The technology/equipment type set involved in each sub-system can be summarized in *Table 1*. The integration of the identified technologies/equipment are necessary for the RAAS to run but not limited to other technologies/equipment that can enhance its performance [27].