Motor-assisted floating function for Frencken high-end patient table

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Motor-Assisted Floating Function for Frencken High-End Patient Table

A System Engineering Approach for the Development and Implementation of Motor-Assisted Floating Module for a High-End Medical Imaging Table

Executive Summary

October 2019

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Public Executive Summary

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The design that is described in this report has been carried out in accordance with the rules of the TU/e Code of Scientific Conduct.

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Abstract	Advanced radiology systems are being widely used for diagnostics and minimally invasive procedures. Key components on these interventional X-ray guided systems are multi-axes patient tables and C-arm scanners. Patient tables with several degrees of freedom in combination with C-arm scanners are utilized to position the patients during the imaging and interventions. In some cases, surgeons and operators position the patients by manually pulling and pushing the tabletop without any motorized movements, which is called manual floating mode. The weight on the tabletop, including the patient and the accessories, can be as high as 300kg. Consequently, the manual positioning efforts can be hard and even harmful for operators in such a way that in the long term, they can have arm and shoulder problems. In this project, a modular product which enables motor-assistance for manual positioning operations to decrease the operator applied forces is developed. Using this function enables the operator to move the loaded surgical patient table with less human input force. In this report, the approach that was followed to develop this product, implementation and the results obtained from the end product are presented.
Keywords	Motor-assisted, Medical imaging table, Velocity control, EtherCAT communication
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Foreword

Within Frencken, we have developed a high end patient table used in Interventional Radiology, Interventional Cardiology, and Interventional Neurology. Continuously we are looking for innovative modules that can be added as extra modules to these tables to even more differentiate the possibilities and ease of use of our table with respect to competitors. By these innovations we offer unique solutions to the end customers like radiologists, cardiologists and neurologists.
One of the selected added value elements will solve the problem that manual movement of a table loaded with a patient usually is physically a heavy task for the medical operator. In a previous project at Frencken, with a student from the TU/E we investigated solutions for haptic feedback which has led to a demonstrator of a motor assisted manual movement only in the longitudinal movement. The success of this student project has led to this design project in which we invited a PD-Eng student (the author of this report, Sahar Etedalidehkordi) to design a demonstrator module that could assist the movement in both the lateral as well as the longitudinal direction simultaneously.
This report reflects the results of this one year assignment. We at Frencken are very happy with the way this project has been conducted by Sahar and the demonstrator that clearly shows the benefit of this function for the end customer. We also thank the cooperation with the supervisor from the TU/e in this project, prof. Dr.ir. René van de Molengraft. This project has led us to the next level of industrialization of this concept and the report is an excellent document to be used in successive projects.

Dr. Jan P. van den Brink
Director Frencken Engineering

October 17^{th} 2019

Preface

This report is part of the final project of the Professional Doctorate in Engineering (PDEng) program in Mechatronics System Design (MSD). The work contained in this report was a collaboration with Frencken Europe company and Eindhoven University of Technology.
The main goal of this project is to design and implement motor-assisted floating functionality to Frencken high-end patient table. The first part of this report is interesting for readers who want to have an overview of the context and challenges related to imaging patient tables and system engineering approach for development process.
The second part of this report is intended for domain experts in the fields of motion control, system identification and embedded systems.

Sahar Etedalidehkordi October $7th$ 2019

Acknowledgements

During my final project, apart from having the opportunity to engage in technical challenges, I was able to grow personally and professionally in multiple ways.
Special thanks to my company project supervisor Dr. Jan van den Brink for giving me the opportunity for learning and professional development. I would like to express my special appreciation and thanks to Ir. Erdem Cerit for being a fantastic mentor for me. If there was an award for best supervisors for these projects, he deserved to be awarded. Furthermore, I would like to express my gratitude to my supervisor Dr.ir. M.J.G. (René) van de Molengraft for the useful comments, remarks, and engagement through the learning process of this project.
I'm especially grateful to Dr. Peter Heuberger for the great opportunity to be part of the MSD community and for the support provided throughout these two years. I'm also grateful to Ellen van Hoof-Rompen, for all the day-to-day support provided.
I would also like to thank the experts who were involved in the validation survey for this project: Eduard Fleerakkers, Dr. Peter Loh and Dhr. dr.Maarten Loos. Without their passionate participation and input, the project could not have been successfully conducted.
My thanks to the entire Engineering team of Frencken Europe company, in particular, Jeroen Hoedemaekers, René Jacobs and Dries van der Lee, for all the productive talks, the collaboration and ultimately creating a friendly environment to work. Also, I would like to thank all of my colleagues in the generation MSD 2017 for all the nice memories, advice and support.
Last but not least, I would like to thank my loved ones, who have supported me throughout the entire process, both by keeping me harmonious and helping me putting pieces together. I will be grateful forever for your love.

Sahar Etedalidehkordi
Eindhoven, October 17^{th} 2019

Executive Summary

Minimal invasive procedures are surgical techniques widely used in the medical field, where high-end technical innovations like medical imaging devices (scanners) and multi-axes surgical patient tables are utilized. The scanners provide X-ray images in real-time, thus allowing the surgeon to monitor progress and immediately make any decision.
Patient tables are used to orient the patient based on the area of interest during the scanning. Sometimes, motorized functionalities of the tables are used to move the area of interest to the focus point of the C-arms, or in some cases, operators manually position the patient by pushing and pulling the tabletop on the horizontal plane. Mostly, manual movement of the table when a patient is on the table requires a large input force from the operator, which can cause injuries such as repetitive strain injury(RSI).
In this project, a system engineering approach is used to design a motor-assisted floating module for Frencken patient table. The approach transformed a set of stakeholders' needs into system objectives that meet those needs. The system objectives define system requirements, synthesizes alternative system designs and evaluate the alternatives to find the best system design.
A user interface is designed to interact with the human, initiate the movement and generate the reference commands for the motor movements.
A prototype is implemented with the aim to be as close as possible to the final product that can be integrated into the Frencken patient table. The prototype module can fit in the user interface to control the table in floating mode.
To show the performance of the design, a demonstration set-up of the functionality is implemented successfully. The results show that the control design is stable and provides power-assistance to the operator to move the table in the floating mode. Having the motor-assisted floating module, the input force required to move the loaded table is reduced to the force which is required to move the empty tabletop. Besides, thanks to designed haptic feedback and virtual damping, the operator can feel if the tabletop is close by the end stop. Therefore, the collision of the tabletop with the end stop during floating movement is prevented.
Finally, to verify that the system requirements are satisfied, the performance of the implemented functionality is tested and approved by one of the end-users (Radiologist at Máxima Medisch Centrum Veldhoven).

1 Introduction

This chapter provides an introduction to the project and how it fits in the Frencken Group B.V. scheme and healthcare systems improvements.

1.1 Project Context

Although radiology is often thought of as a diagnostic field, it has become increasingly involved in the development and deployment of treatment modalities. It has been used in several minimally invasive therapeutic procedures in different applications like Interventional Radiology, Interventional Cardiology, and Interventional Neurology. [1]

Cardio / vascular surgical procedures use X-ray images taken by C-arms during surgery as intervention guidance. Figure 1.1 shows a typical example of C-arm scanner and a medical imaging table.

Figure 1.1: C-arm scanner and medical imaging table [2]

Moving the patient into the best viewing position for scanning is a common surgical task, which requires experiences, time, and sometimes many X-ray shots until the desired image is obtained [3]. Accordingly, positioning the patient in the proper position is difficult to accomplish.

For applications that use a fixed C-arm scanning machine, the patient table should have sufficient degrees of Freedom for numerous activities like tracking the guidewire. At the moment, fully motorized patient tables can help the operators to accurately position patients in the scanning area. However, the procedure for aligning patients with motorized tables is time-consuming and tiresome. Consequently, most surgeons instruct the assistants to move the table with the patient or prefer to position the patient with manual hand-grips. Manually pushing the table with the patient over it requires more input force which may eventually create medical issues to the surgeon's arm/shoulder.

Motor assistance is a technology that utilizes the force capabilities of the motor and the decision capabilities of the operators to handle heavy systems easier with less force from the operator side. In day to day life, motor-assistance is seen in electric bikes, load-lifting devices and electric wheelchairs for the elder people[4],[5]. Motor assistant technology is also significant in the healthcare sector as it can enable easy and time-saving diagnostic and treatment methods[6],[7]. This project investigates the notion of motor assistance on a surgical patient table.

1.2 Project Partners and Objectives

The project was carried out in collaboration with Frencken Group B.V. and the Eindhoven University of Technology. This section will describe better the main project partners and their roles and interests.

1.2.1 Frencken Europe B.V.

Frencken Europe B.V is a part of Frencken Group which is a holding with several companies world-wide, in Europe, the US, and Asia. Figure 1.2 shows the company structure. Frencken Europe is a high tech service and (sub-)system provider mainly for three industries: Heathcare, Semiconductor and Analytics. This project is one of the development projects in the Healthcare section. The area of interest in this section is product development, supply chain management, assembly, test and product life cycle management.

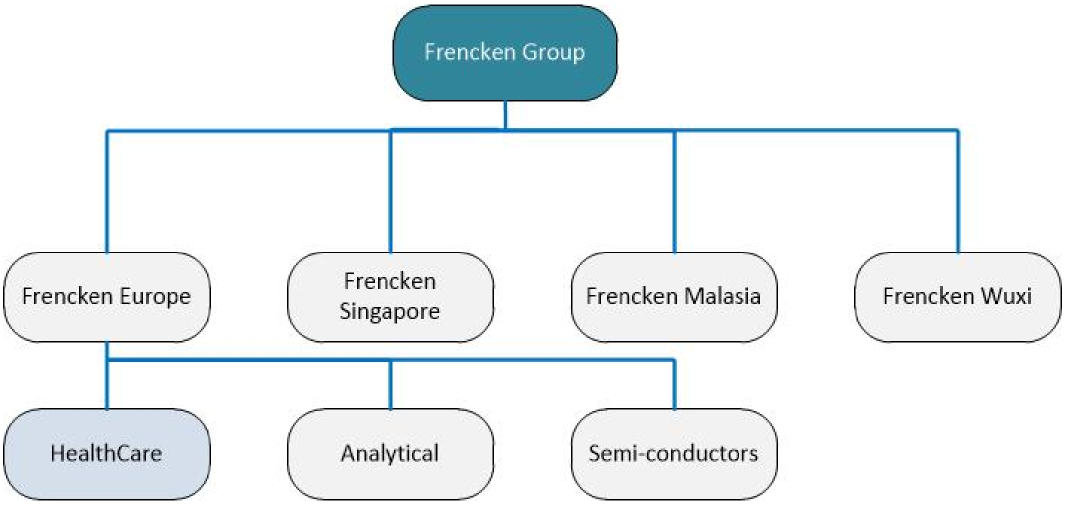

Figure 1.2: Frencken company structure

1.3 Project Scope and Boundaries

It is important to narrow down the scope of the project and set priorities to improve the quality of the work. For each project, a balance between the scope, the cost or resources and the allocated time for the project needs to be considered. In this project the allocated time and resources are almost fixed, therefore major changes or compromises need to be made on the scope to ensure the product quality.

It worth mentioning that balancing for the scope is an iterative process and was regularly evaluated against available time and resources to adjust the scope accordingly. To this end, the final iteration of the defined scope for the project is presented below.

- In scope
  - Analyze the system structure and research the system requirements for adding motor-assisted functionality
  - Analyze and improve the already available longitudinal axis motor-assisted floating function
  - Simulate, design and implement the integrated lateral and longitudinal motor-assisted floating function
  - Specify and select the hardware suitable for implementation
  - Specify and design the user interface module
  - Functional test of demonstration set-up
- boundaries
  - The mechanical design of the user interface module will be created with the help of Frencken mechanical engineering. Also, supports can be provided from system engineers at Frencken for the electrical design of components.
  - Simulation, design, and implementation of the floating function for the lateral axis will be obtained with the help of a master student from TU/e
  - with the current table structure, floating tabletop is not possible if the table is tilted or cradled. This limits the scope of the project for horizontal movements on X-Y plane

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