

## Medical robotics

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Medical Robotics  
Design of a master manipulator for a  
laparoscopic forceps

first traineeship

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## Abstract

A surgery technique that is often used in the operation room is Minimal Invasive Surgery (MIS), sometimes called 'key-hole surgery' since operations are being performed through relatively small openings in the body. Performing surgery with this technique means a big improvement for the patient, however for the surgeon some disadvantages appear, such as that the surgeon has no longer visual 3D feedback but only a 2D image. Furthermore there is a need for special MIS tools to perform the surgery in a limited workspace and that may, for instance, be an advanced master-slave system. However, a big disadvantage in using a master-slave system is the complete lack of haptic feedback, i.e. the surgeon does not feel what he/she is doing. Creating a master-slave system with bilateral feedback (visual and force feedback) improves the circumstances in which the surgeon has to perform his surgery.

During this traineeship the master manipulator of a master-slave system with 1 DOF is designed, built and tested. The master-slave system replaces a laparoscopic forceps (kind of gripper) a surgeon often uses during surgery in the abdomen. The position of the gripper at the slave side is meant to be visually fed back to the surgeon, while there is also force feedback (being part of haptic feedback) in order to let the surgeon at the master side 'feel' the contact force between the gripper and the body.

In the master system, a DC-motor is chosen for a 'correct' delivery of torque, such that the surgeon senses the torque measured at the slave side (and a closer look is taken at what is actually meant with haptic sensing). Furthermore a position sensor is added for position measurement, so the position can be fed back to the slave in order to let it react on the movement imposed by the surgeon. For controlling the DC-motor, a current amplifier is used and after building the master system the control strategy is tested. Afterwards, some system identification is performed, so future analysis and simulation of the master in combination with the slave can be performed. Finally it is shown that the master system is accurate and capable of delivering force feedback to the surgeon.

# Chapter 1

## Introduction

Today's surgery is performed with more and more advanced techniques. The operation room is full with computers that supervise the vital live signs like blood pressure, pulsation of the heart and regulates the artificial respiration. Powered robots are used as passive tool holders or holding fixtures at an appropriate location. Complex artifacts may be used by the surgeon, for example the endoscopic grasper, to perform minimal invasive surgery. While robots are commonly used for industrial goals, in the operation room such robots are still not widely introduced.

This chapter handles the advantages and disadvantages of Minimal Invasive Surgery, which may be realized with the help of robots. So there is a great task for surgeons and engineers to combine the medical needs and technical possibilities.

### 1.1 Minimal Invasive Surgery

An operation technique that is often used in the operation room is Minimal Invasive Surgery (MIS). This kind of surgery is performed by making small incisions, which vary in size from 5 mm to 12 mm (Minimal), through which special instruments can be introduced (Invasive). These kind of incisions are also called 'keyholes' and the number that is needed to perform surgery vary between 3 and 6. One of those holes is used to create a visual image outside the body: a small telescope is introduced into the cannula and is connected to a video monitor that creates a 2D view. Often, one of the other incisions is used to insert a gas or liquid to create more space in the surgical area (for example CO<sub>2</sub> gas is inserted during laparoscopic surgery performed in the abdomen). Additional ports are typically required to place special instruments to operate [1], such as a grasper shown in figure(1.1). Already many surgeries are being done utilizing this technique with good results in general surgery, gynecology, pediatric, chest, orthopedic, urology and vascular surgery. And research is done to perform this kind of surgery to all parts of the human body. For example, at the UMC (Utrecht) research is done at the less invasive coronary bypass surgery [2].

The technique of MIS provides very big advantages for the patient: by decreasing the damage to the tissue by making the incisions smaller, the patient recovers faster and with less pain. Also for the society this gives advantages: the patient is faster active in the society (so less costs) and a hospital bed is free earlier (so waiting lists decrease).

However, there are some disadvantages for the surgeon: by performing keyhole surgery the surgeon can no longer use some skills that were easily applied with open surgery. For instance, the surgeon has no longer a 3D visual feedback but only can look on a 2D video screen. Furthermore, the movement in the body of the patient is decreased a lot and the surgeon can no longer touch and feel the tissue with his/her hands, so less contact experience reaches the surgeon. To solve these



Figure 1.1: A laparoscopic forceps

problems that are related to MIS, a solution is supposed where engineers play an important role. The first problem with respect to the visual feedback can be tackled by means of advanced imaging and data processing. In this project we have focussed on the second problem that is related to the lack of haptic feedback during MIS. First, we have to consider what haptic feedback is.

## 1.2 Haptic sensing

A sense that is completely underestimated is touch, while touch for a human being is very important in most situations. With respect to surgery touch can help determine, for instance, stiffness, viscosity, weight and roughness. But how does touch work? For not going too much into detail, here only a few definitions are given and not the whole biological background of this kind of sensing [3]:

**tactile sensory:** The definition of a tactile sensor is :‘a device which measures parameters of a contact interaction between the device and some physical stimulus’. Tactile sensing provides data on, for instance, one of the following data: size, shape, position, thermal conductivity or distribution of forces of a contacting object and torque. Human tactile sensing can be divided in two groups of sensing, which are known as kinesthetic and cutaneous components.

**kinesthetic:** The kinesthetic information arises out of muscle and joint signals of the whole hand and arm, so by knowing the position of the corresponding links the shape of the touched object is reconstructed.

**cutaneous:** The cutaneous information is derived from sensors on the fingertips. For instance information about pressure and thermal conductivity.

**haptic:** Haptic sensing is the combination of kinesthetic and cutaneous sensing.

Hence, from haptic sensing one gains a lot of information, especially when considering surgery: the surgeon can feel his/her way around the tissue, can cut where he/she thinks the tissue is the less vulnerable and so on. Removing this haptic feeling removes the quality of surgery. Some

improvements have already been developed, such as the master-slave systems ‘DaVinci’[4] and the ‘Zeus’[5]

### 1.3 Master slave systems in surgery

Robotic systems already in use in operation rooms are so-called master-slave systems. In general, a master-slave system is a system which contains 2 components: a master and a slave with no mechanical link in between (but electronics and a computer instead). Master-slave systems that are used for commercial goals are, for example, so called 'drive by wire' or 'fly-by-wire' systems, where the information of the pilot is digitally send to the air-plane motors, flaps etc. An example of a master-slave system in an operation room is the 'DaVinci' system. With this system, surgeons can perform surgery even without being in the same room as the patient. The surgeon controls the master and the master sends information to the slave about the desired movement and position. Another benefit of this system is the image processing: the created image of the area of surgery can be up-scaled 10 times. Furthermore, by downscaling the measured movement of the surgeon the tools at the slave side can be positioned more precisely than the surgeon can do. This system can also filter tremor of the surgeons hand and the robot can stay in every position for a long time, something which is not always possible for a surgeon. These machines are promising but the surgeon still does not obtain any haptic information.

Nevertheless, for master-slave systems it is possible to partially realize haptic feedback by means of force feedback: the slave can be adjusted to measure the force/torque at the slave side and the master can be adjusted so that an actuator can supply this force/torque to the surgeon. This idea of a master-slave system with force feedback has been applied to a laparoscopic forceps (see figure(1.1)), with 1 degree of freedom (DOF) being the opening and closing of the grasper. The slave part of this system is extensively discussed in 'A SMA actuated laparoscopic forceps with force feedback' by Peeters [6]. The goal of this project is designing, building and testing the master part of the maser-slave system.

In chapter 2, the design of a master laparoscopic forceps is discussed: what kind of actuator is used and what kind of measurement is needed to provide enough information for the slave. Also a scheme is given how the interaction between master and slave should be. In chapter 3, some simulation results with constrained movement are shown and control strategies are discussed. In chapter 4, experimental results obtained with the master system are presented. Finally, in chapter 5 conclusions and recommendations for further research are given.

## Chapter 2

# The design of a master manipulator

### 2.1 Master slave configuration

For the design of a master manipulator for the laparoscopic forceps, there must be some design requirements. To do so, a schematic representation is given for the interaction between master and slave. In case there is force feedback (in case of no force feedback, the force fed back from the slave to the master to the surgeon,  $f_s$  resp.  $f_m$  is removed). The master and slave are not

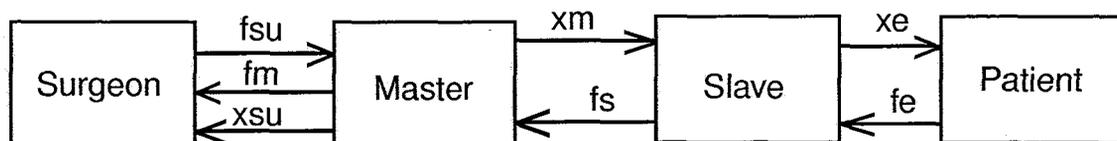


Figure 2.1: A schematic representation of the master slave system

mechanically linked, but electrical/digital information is sent to each other. The desired position (given by the surgeon's hand) measured at the master side, is the input for the tactile feedback to the slave. And the force/torque measured at the slave side is the input for the master. Since the slave system has already been developed and to acquire some design requirements, a closer look is taken to the master side.

### 2.2 Experimental Setup of the Master System

To create an experimental setup in which the master manipulator can be tested, first a closer look at figure(2.1) is needed. The surgeon-master part is selected and presented in figure(2.2).

$x_{ref}$  = position or trajectory defined by the surgeon  
 $x_s$  = visual information about the position of the slave  
 $f_{su}$  = force imposed by the surgeon on the master system  
 $f_m$  = force imposed by the master system on the surgeon  
 $x_m$  = position displacement of the master system =  $x_{su}$  in figure2.1

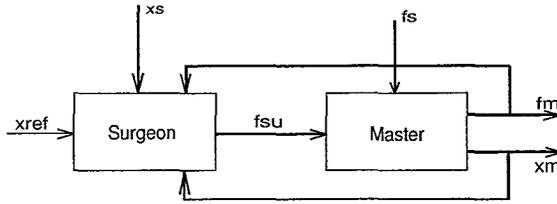


Figure 2.2: master-surgeon

The surgeon act as a controller with multiple inputs and one output, that varies during constrained or unconstrained movement (during unconstrained movement only  $x_s$  and during constrained movement  $x_s, x_m, f_m$ ). The position of the slave  $x_s$  and the force of the slave  $f_s$  are only useful when the master and slave are coupled, so for now the position and force of the slave will be ignored. The surgeon applies a force to the master  $f_{su}$  such that the trajectory defined by the surgeon  $x_{ref}$  is followed. By changing the position of the master  $x_m$ , the contact forces  $f_s$  at the tip of the slave will change. The surgeon can feel this when the force delivered by the master system  $f_m$  will change the same amount.

The system requirements are therefore:

1. A contact area has to be present, where the surgeon can manipulate the master system.
2. The position displacement has to be measured for transfer to the slave.
3. A manipulator is needed for correct delivery of torque to the surgeon.

### 2.2.1 Position measurement

There are, of course, different ways to design a tool for describing a desired trajectory for the master-slave system, for example the the DaVince master-slave system uses joysticks for this action. However, since the design has to be one for a laprosopic forceps the original handles of the scissors are used (see figure(1.1)). The advantage of using this setup in stead of a joystick is the fact that it react's and feels exactly like a normal pair of scissors; a disadvantage is that the working space of the angle is relative small,i.e. less than 1.57 rad. Hence a high quality sensor is needed that is accurately enough for measuring the small motion of the surgeons hand.

The specifications of the sensor choosen for the experimental setup is the two channel optical incremental encoder in combination with a 500 counters codewheel. The resolution achieved with this encoder is  $\frac{2\pi}{2000} [rad]$ .

### 2.2.2 Actuator

First of all, one has to consider what kind of actuator there is needed for an accurate force/torque representation and, before that, we have to consider whether a force or a torque is represented to the surgeon. Since we decided to design a scissors-like system for the hand of the surgeon, an actuator was chosen that can provide an adequate torque. Typical forces that appear during MIS are about 1.5 [N] for driving a needle into a tissue and 5 [N] for grasping tissues. The maximum torque that is measured at the slave side in the experimental laparoscopic forceps of Peeters[6], is 0.03 [Nm]. An obvious choice for an actuator is a DC-motor available in our lab that, according to the specification [7], produces 5 times (150 [mN.m])as much torque than is needed.

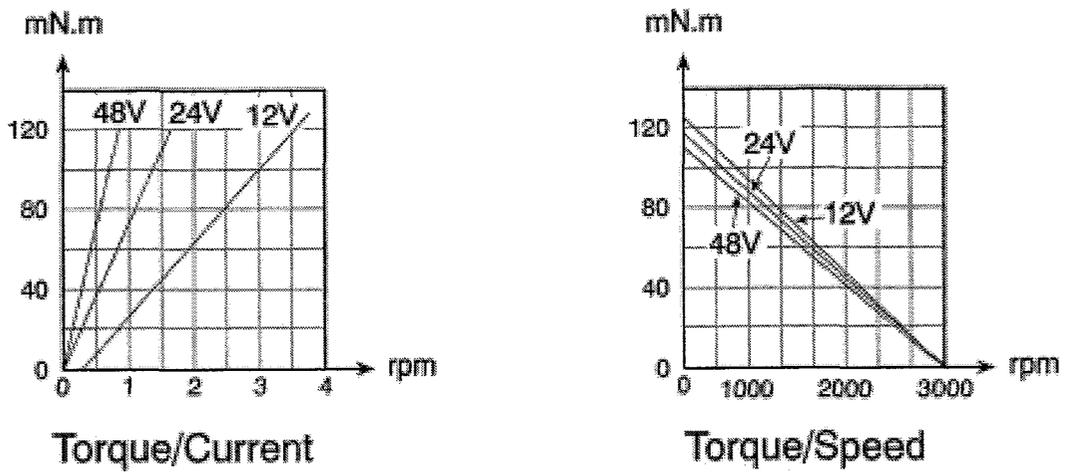
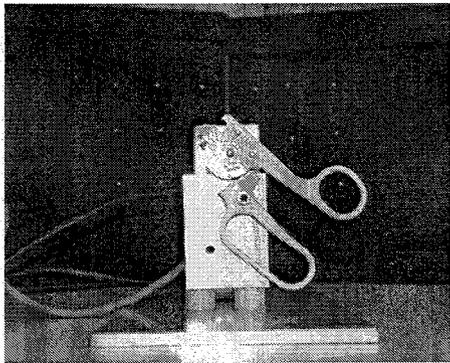


Figure 2.3: torque current and torque velocity curves

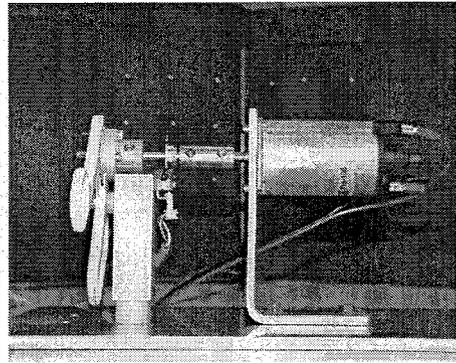
Hence, this DC-motor is far more capable of producing the necessary amount of power, there is even a possibility for upscaling the torque measured at the slave side. Furthermore, the current is, according to the product information (figure(2.3)), linearly related to the torque of the motor. The only disadvantage of this DC-motor is the fact that a human hand can push through the maximum torque delivered by the motor (when holding a rigid body at the slave side, the handles can close till it reaches the closed position).

### 2.2.3 Final Setup

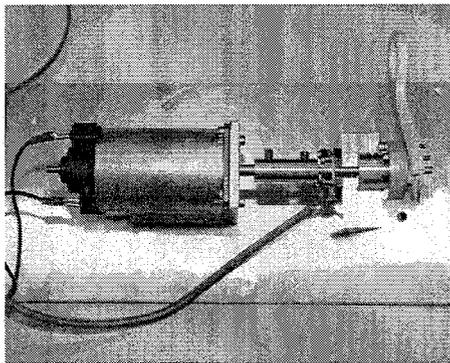
Assembling the sensor, the handles and the motor gives the final setup of the master manipulator of the laparoscopic forceps shown in figure (2.4) . If needed the handles can be placed for a right handed as well as a left handed person.



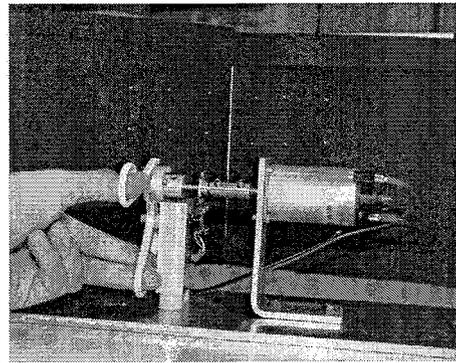
(a) front view



(b) side view



(c) top view



(d) action

Figure 2.4: Different views of the master system

## Chapter 3

# Modelling and Simulation

In this chapter the dynamics of the master system of the laparoscopic forceps is discussed. Furthermore, a control strategy is developed for ensuring that the surgeon will feel the actual (or upscaled) torque, measured at the slave side.

### 3.1 Model of the 1D master manipulator

The differential equations of the 1D master manipulator are those of the linear DC-motor, since the setup contains the DC-motor with a rigid link to the handle. These handles have some influence on the total inertia; the amount of influence is discussed in chapter 4. For deriving the equation of motion, a schematic representation of the DC-motor is given. [8]

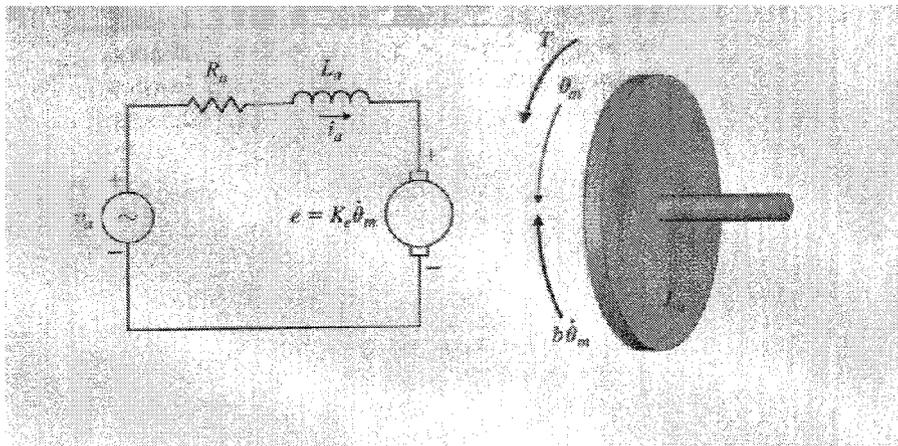


Figure 3.1: schematic representation of the DC-motor

It is necessary that the mechanical part as well as the electrical components are included in the model, because the electrical components have a significant influence on the torque delivered by the motor.

The mechanical part can be described by,

$$J_m \ddot{\theta}_m + b_m \dot{\theta}_m = K_t I_a + T_{load} \quad (3.1)$$

$T_{load}$  = the disturbance torque, i.e. the torque delivered by the surgeon.

$K_t$  = the motor constant.  
 $J_m$  =Inertia  
 $\theta_m$  = angle displacement  
 $b_m$  = viscous friction  
 $I_a$  = current

The electrical part can be described by,

$$K_e \dot{\theta}_m + L_a \frac{dI_a}{dt} + R_a I_a = v_a \quad (3.2)$$

$K_e$  = the back emf (electromotive force) caused by the shaft rotation velocity. With ohm's law  
 $I_a = \frac{v_a}{R_a}$  the current and so the torque can be derived  
 $L_a$  Inductance  
 $R_a$  Electric resistance  
 $v_a$  voltage input

The total equation of motion is, after joining equation (3.1) en (3.2),

$$J_m \ddot{\theta}_m + b_m \dot{\theta}_m = \frac{K_t}{R_a} (v_a - L_a \frac{dI_a}{dt} - K_e \dot{\theta}_m) + T_{load} \quad (3.3)$$

For the simulations, the assumption is made that the inductance  $L_a$  can be neglected. Furthermore because the electrical circuit response is much faster than the rotor motion,  $L_a$  is very small:  $L_a \ll 1$ .

## 3.2 Control strategy for master manipulator

Since it is important that the torque delivered by the motor is the correct one, it has to be controlled. In the uncontrolled way (3.3), the current and torque of the motor will rise by adding a  $T_{load}$ , otherwise causing the back emf the current of the motor will decrease. So, by feeding back the current and multiplying this with a gain will suppress the effect of the disturbance load and the back emf, i.e. proportional control. Furthermore, integral control is needed for compensating the steady state error. Derivative feedback can be added but is not needed since the case of force feedback take place quasi-static.

In practice, this software PI-controller is replaced by a hardware current amplifier, which takes care of a linear relation between the voltage that goes into the motor and the current/torque that consequently is supplied by the motor. The bandwidth of this current amplifier lies in the order of kHz.

## 3.3 Simulation of force feedback

The derived equation of motion (3.3) of the master system can be implemented in simulink matlab as shown in figure(3.2)

The open loop simulation of the master system (i.e. without the surgeon) gives information about the input (voltage  $V_a$ ) and output (angle displacement  $\Theta_m$ ) relation. Two interesting results are: the drop of current as a result of the back emf (see figure(3.3) and the increase of current while adding a disturbance load. To conquer these two problems, a current amplifier is added as controller (instead of a PI-controller as discussed in section 3.2). The current amplifier controls

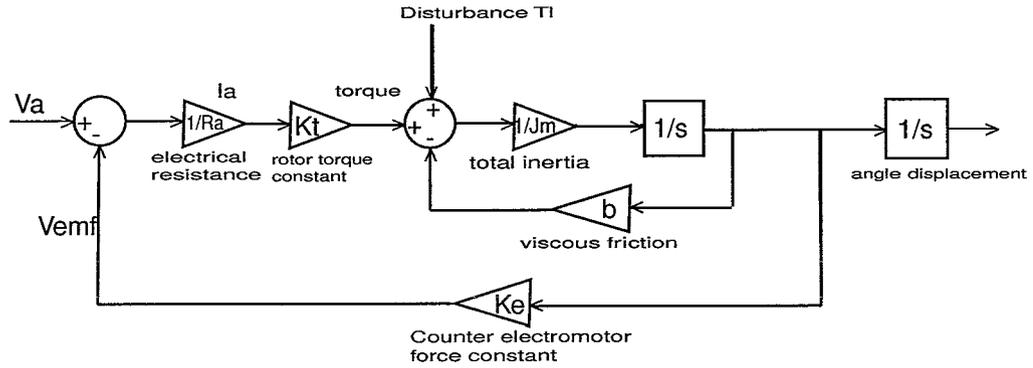


Figure 3.2: Implementation in simulink

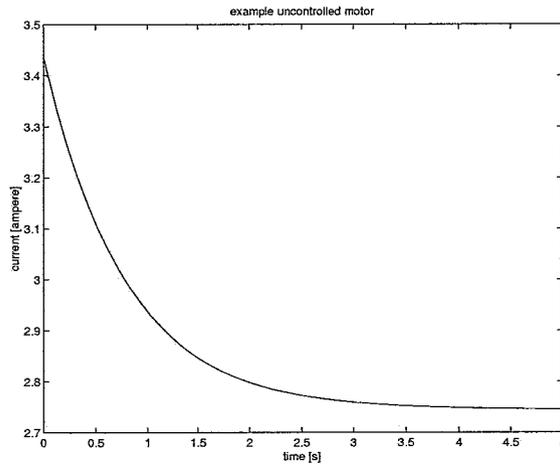


Figure 3.3: time response of the uncontrolled motor

the current as a PI controller: in this way, influences of the back emf and other disturbances are suppressed. After adding the current amplifier, equation (3.3) can be written as:

$$J_m \ddot{\theta}_m + b_m \dot{\theta}_m = \alpha v_a + T_{load} \quad (3.4)$$

This gives a (linear) relation between the input  $v_a$  and the torque delivered by the DC-motor. In figure(3.4), the current is simulated with a constant input voltage (the current is no longer dependent of other factors than the input voltage). In a quasi-static case ( $\dot{\theta} \cong 0, \ddot{\theta} \cong 0$ ), equation (3.4) is simplified to:

$$\alpha v_a = -T_{load} \quad (3.5)$$

To complete this master system, it has to be calibrated such that the relation between the imposed voltage  $v_a$  and delivered torque is known (i.e., such that  $\alpha$  is known). This will be done in chapter 4, (section 4.1).

### 3.4 Model of the surgeon

Since it is a hard task to define haptic sensing of human in technical terms, a suggestion is made in the following paragraph. But first, to simulate the surgeon at the master side, the dynamical

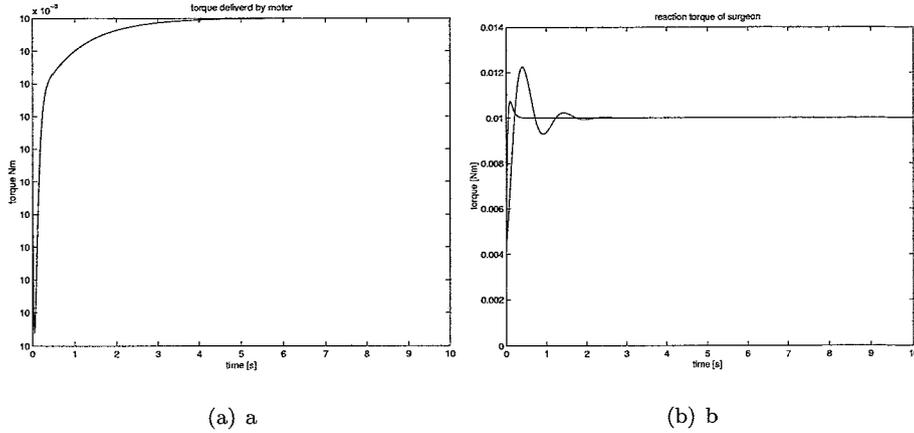


Figure 3.4: (a)torque controlled motor, (b) simulated surgeon

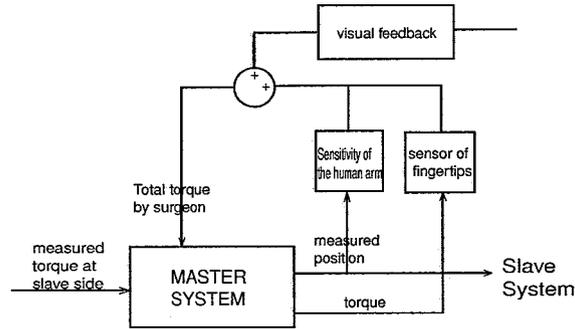


Figure 3.5: model of surgeon

behavior of the human hand has to be described. It is still not clear whether the human hand behaves like a force or a position control system, but it is well known that the human hand can do both. Therefore the definitions of cutaneous, kinesthetic and haptic feeling made in paragraph 1.2 are used. The model of the surgeon in interaction with the master slave system can be represented as shown in figure(3.5). The sensitivity of the human hand maps the master robot position constraint onto the contact force, this can be seen as the kinesthetic feeling of the human hand. The sensor of fingertips is an additional one and may be interpret as the cutaneous feeling. The bilateral feedback is well defined in the picture: the visual position feedback is the first unilateral feedback and the force feedback is the other unilateral feedback. By combining the master and the slave, a bilateral feedback is created.

It is clear that this sensitivity plays a big role in the stability of the human hand. It is not clear how the sensitivity of the human hand exactly looks like, but it is expected that it is similar to that of the human arm [9]:

$$S_h = 0.1 \left( \frac{s^2}{2.52} + \frac{s}{2.19} + 1 \right) \left[ \frac{cm}{N} \right] \quad (3.6)$$

In figure (3.4), the closed-loop system of the surgeon in interaction with the master system is simulated. The input is a constant voltage and the output is the torque delivered by the motor (plot left) and the torque by the surgeon (plot right). Note, that in this simulation the blocks with 'visual feedback' and 'sensor of fingertips' are not taken into account. Different parameters are used for the sensitivity function of the human hand; all kinds of dynamical behavior of the human hand can be simulated: in the right plot you can see -for example- the results obtained with a hand

that reacts fast with much/less damping.

# Chapter 4

## Testing the master manipulator

### 4.1 Calibration

In our experimental setup, a current amplifier is used as 'control strategy' (i.e. representing a PI controller), and it is supposed that we have an 'ideal' controller: each voltage is linearly related to a current and so linearly related to a delivered torque. The relation between current and torque is known on basis of the specifications (product information) of the DC-motor. The input signal on the motor is voltage and the relation between voltage and current is measured with the help of a multi measurer. This gives the linear relationship as shown in figure(4.1), which is expected from ohm's law, with a coefficient of  $0.7[\frac{A}{V}]$ .

Experiments with the master system have been performed with the help of a computer in-

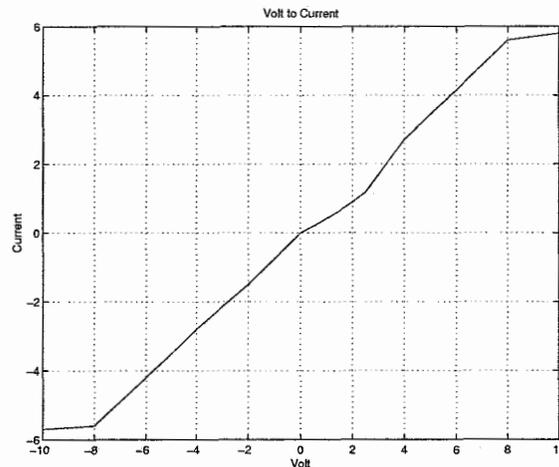


Figure 4.1: The voltage to current curve

terface, Dspace, in which each input value is multiplied with a factor 10 (hence, this has to be compensated with a factor 1/10 in the software). At 8 [V] saturation occurs, not caused by the current amplifier (which works in a range of  $\pm 10[V]$ ) but caused by a manually inserted safety margin. In this way, the DC-motor can deliver enough torque without getting the surgeon in a dangerous situation. Next to this first safety constrained the second one is a position constrained: the motor is only enabled when the angle between the handle is less than  $\frac{\pi}{2}$ .

The torque delivered by the motor is measured with an analog force sensor, with a maximum capacity of 5 [N]. The sensor is perpendicular placed on the handle of the grasper. By multiplying the measured force with the length of the arm, one yields the torque delivered by the master system.

In figure 4.2, the twisted curve is the measured torque and the straight curve is the predicted torque (on basis of the product information of the DC-motor) as function of current (obtained from voltage by multiplying it with  $0.7[\frac{A}{V}]$ ). The torque is measured in a static position, which is the same as when grasping an object or slowly manipulating the master system.

Around zero [V], the torque delivered by the master system remains at zero [Nm]. Apparently, at

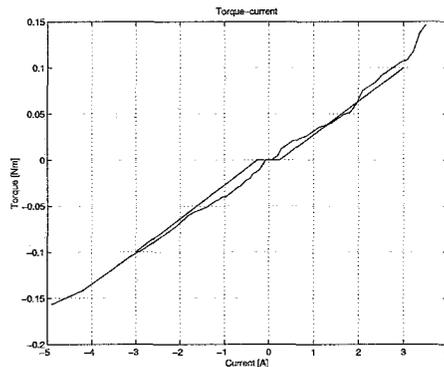


Figure 4.2: The calibration of torque

low input voltages the master system is not capable to conquer the static friction that is working in the DC-motor. It is not exactly known at what voltage the motor begins to deliver a torque that is more than the static friction. The values varies between 0.17 [V] (the measured value) and 0.35 [V] (the value given in the product information). The variety of the values are caused by the way of measurement: the measurer is not completely rigid fixed and the resolution is 0.1 [N]. Despite of the slight differences caused by uncertainty of the measurement, the curves are close enough to each other to assume that the product information gives the correct current-torque relation.

Now the voltage-current and current-torque relation is given, the voltage-torque relation is known. By defining the negative torque in the counter clock wise direction (the direction in which the handles are opening), the controller is completed.

## 4.2 System identification

For future development and simulations (of the complete master slave system), it is preferable to know more about the master system. Not only the product information is used (and verified by means of calibration), but for more system information a frequency response can be helpful.

The frequency response of the master system is achieved by measuring the sensitivity function of the plant controlled by a PD-controller,  $k_p = 0.5[\frac{V}{rad}]$  and  $k_v = 0.05[\frac{Vs}{rad}]$ . The sensitivity is measured with TUDACS, because dSpace was not available at that time. A sample frequency of 500 Hz was used with a noise intensity of 0.0025 [V]. The sensitivity function was obtained by applying the TFE algorithm to the measured output signal of the controller and the input signal of the noise. By 'dividing' this sensitivity function by the PD-controller function, the frequency response of the master system is found. Two different configurations of the master system are examined: that of the master system without (1) and with (2) the handles of the grasper.

The first master system configuration that is examined is the one without the handles. The motor is spinning with a constant velocity: in this way, the coulombs friction is compensated and has no influence on the plant. This experiment is performed in clock and counterclockwise direction to make sure that the system has the same properties in both directions, according to the covariance, the measurement becomes reliable around 20 Hz according to the covariance. It is

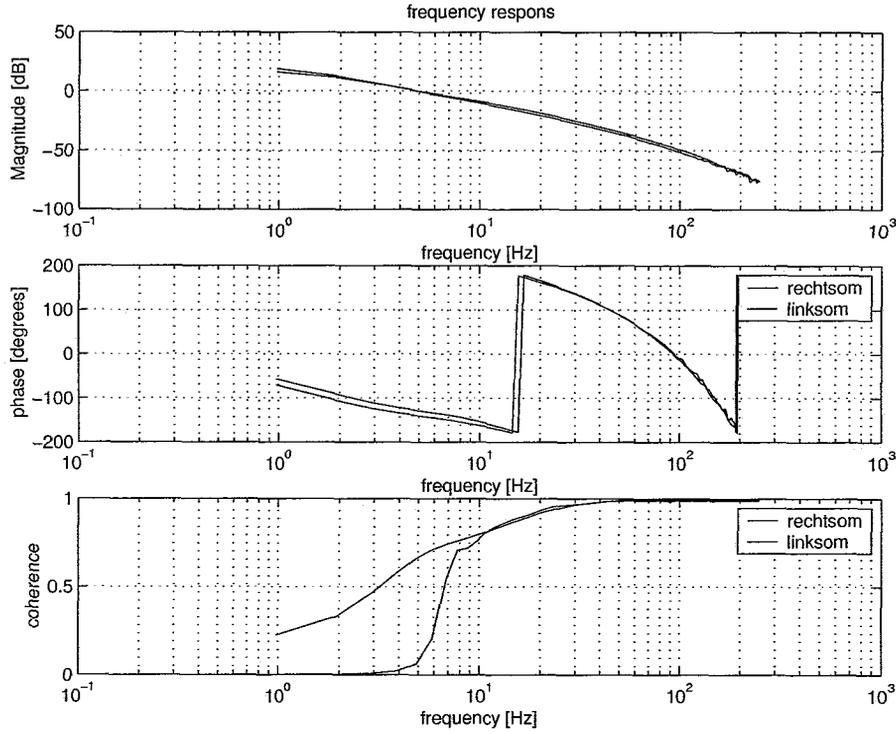


Figure 4.3: Frequency response of manipulator without handle

also clear that there is a considerable time delay, the function for time delay is:

$$H(j\omega) = e^{j\omega Td} \quad (4.1)$$

with  $Td = Tc + \alpha * Ts/2$  (with  $Tc$  the calculation time,  $Ts$  the sample time and  $\alpha > 1$ ).

$$Phase(H(j\omega)) = -360 * Td * f[deg] \quad (4.2)$$

Shows that at a frequency,  $f=1/Td$ , the delay is -360 degrees. If one assume that the calculation time is zero and the sample frequency that is used is 500 Hz (that is used in the experiment),  $Td=1/1000$  and a delay of -360 degrees occurs at 1000 Hz (which do not agrees with the result shown in figure(4.3), since the delay of -360 degrees happens to be at 200 Hz). Therefore, there has to be some additional delay, that is caused by the calculation time, but no further investigation is done at this point.

The magnitude of the plant has a slope of -40dB/Decade in both turning directions (as expected for a second-order system), so the plant has no variations in direction.

The Inertia of the plant without handle which can derived from the frequency response:

$$H(j\omega) = \frac{K}{J\omega^2} \quad (4.3)$$

By solving this equation with the help of the measurement results (figure(4.3), for instance: magnitude -50dB and corresponding angle velocity  $2 * \pi * 100[\text{rad/s}]$ ) and  $K=0.5$ , the inertia we yield, is equal to  $3.95e^{-4}\text{kgm}^2$

The frequency response with handles is measured with a higher sample frequency of 2000 Hz (dSpace) and, hence, the delay is smaller (see figure(4.4)).

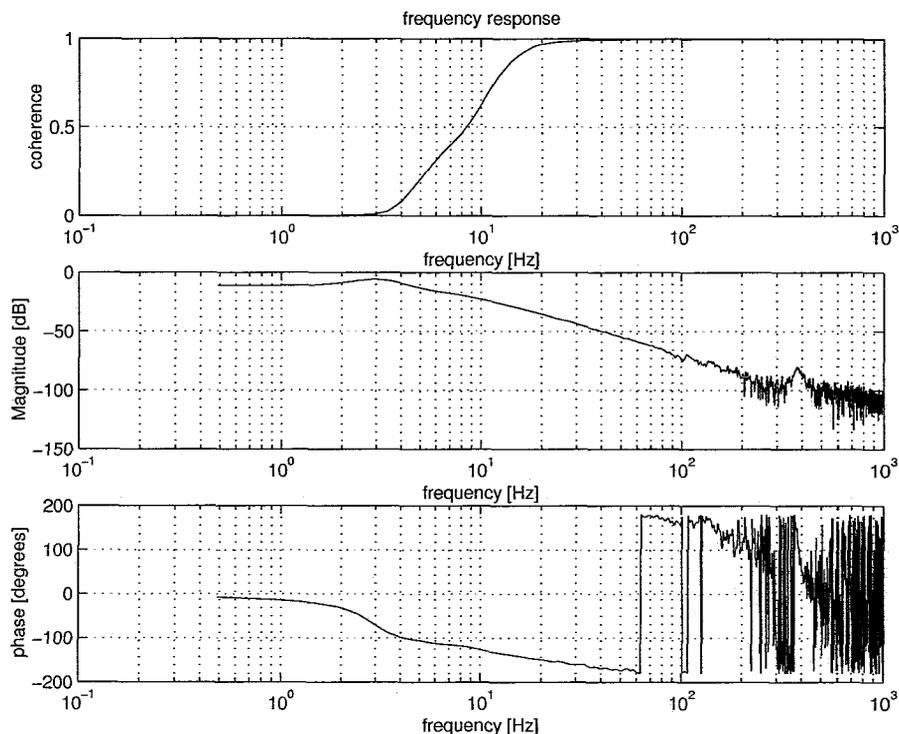


Figure 4.4: Frequency response of the manipulator with handle

Again the reliability of the measurement start around 20 Hz and again a slope of -40dB/Decade is found. In this case the inertia of the plant (taken at 40Hz, -50 dB,  $K=0.5$ ) is  $2.45e^{-3}\text{kgm}^2$ . As expected, the inertia of the system with handles is more then the inertia of the master system without the handles.

### 4.3 Other test results

Next to measuring responses in the frequency domain, one can also do some testing in time domain. By measuring in the time domain, time responses of the master system are achieved and the way the system acts and reacts come forward.

To do so, a mass-spring-damper system is simulated: while pinching the master grasper it feels like pinching in a real object, containing properties like stiffness and damping. To create this, virtual 'object' the measured position of the angle displacement  $\theta_m$  is used as input for a mass-spring system according to equation (4.4), where  $v_a$  is the input torque for the master.

$$v_a = k * \theta_m + J * \ddot{\theta}_m \quad (4.4)$$

Two real time experiments in the time domain are performed: one with an undamped system, see figure(4.5 a) and one with a damped system, see figure(4.5 b). The angle between the handles is decreased by human power and when the handle is in the preferable position it is released.

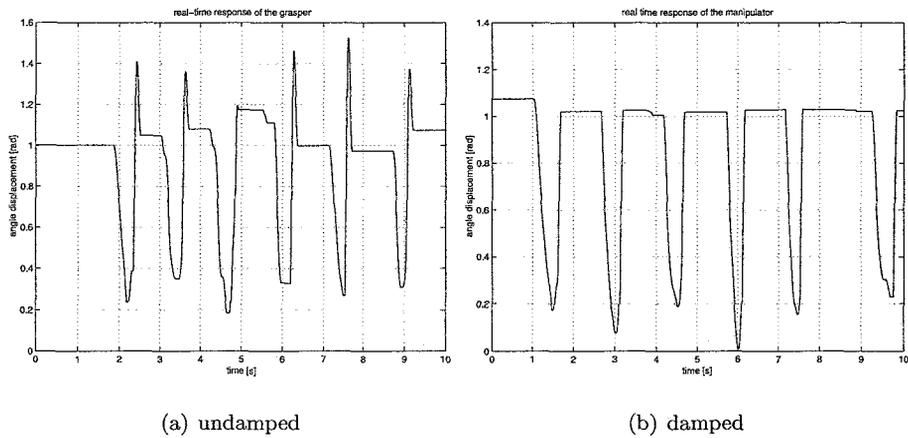


Figure 4.5: time response

The virtual 'object', i.e. the mass-spring(-damper) system, then pushes the handles away and the handles jump open. In the undamped system, the handles should kept moving but since they stop moving some additional damping has to be present in the system. This viscous friction coefficient can not be seen in the frequency response, this could be because the slope of  $-20\text{dB/Decade}$  is present at low frequencies. The damping in the mass-spring-damper system has much more influence then the damping that is mechanically in the master system, therefor the appearance of the mechanically damping is not bad. The torque of the master is indeed capable of reacting as a mass-spring-damper system and is also capable of reflecting the torque measured at the slave side to the surgeon.

## Chapter 5

# Conclusions and recommendations

After a small introduction in the field of Medical Robotics, it seems that there is a need for a surgical master slave system that contains some haptic feedback. Therefore a small experimental master slave system of a laparoscopic forceps is being designed. In this project is focussed on the master system, that is designed, built and tested.

The designed master forceps contains a DC-motor which is qualified to reflect a torque to the surgeon who is controlling the laparoscopic forceps. The capacity of the actuator enables upscaling the torque. A position sensor is added to the master system for measuring the rotation angle, which is needed as a reference for the slave. For manipulating the master system, the handles of the original laparoscopic forceps are used. In simulations of the master system it appears that a controller is needed for a correct delivery of torque. Therefore a current amplifier is used as a kind of 'control strategy', such that there is a linear relationship between the current and torque. After calibration, the applied torque is known as function of the input voltage. During unconstrained movement, with this developed master system the surgeon feels friction of the mechanical system, which can be partly compensated. But since friction during movement of a scissor is a natural, in fact this compensation is not needed.

A suggestion is made for simulating the surgeon, with cutaneous, kinesthetic and visual feedback, and it is shown that the surgeon can have some contact experience, with this designed master system.

Now the master system and slave system of the laparoscopic forceps are both been built, the coupling of these two systems can be investigated. Some filters may perhaps be needed during coupling of the two systems: for instance, to suppress the tremor of the surgeon, or to filter out noise of the measurement signals.

After coupling of the master and the slave system are coupled, research could be performed on the advantages of haptic feedback. This can be done by grasping different materials with the human hand, a forceps without haptic feedback and one with haptic feedback. In this way it may also come clear in what way the human haptic feeling works.

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