Technical report, IDE0828, May 2008

Power Assistant Design

To Enhance Mobility of a Patient Lift

Master's Thesis in Computer Systems Engineering

Vitaly Tsirkin, Ravil Gazizov

School of Information Science, Computer and Electrical Engineering

Halmstad University

Power Assistant Design
To Enhance Mobility of a Patient Lift

Master's Thesis in Computer Systems Engineering

School of Information Science, Computer and Electrical Engineering, IDE

Halmstad University

Box 823, S-301 18 Halmstad, Sweden

May 2008

Preface

The master thesis was carried out at Halmstad University, Sweden, during the winter and spring 2008.

During this project we have got a lot of help from our supervisor Ulf Holmberg, with modelling and digital control part. He also read the thesis and corrected English grammar.

We also would like to thank:

- Tommy Salomonsson, who helped us during developing software, especially drivers for motors and encoders
- Ruben Rydberg, at the electronic workshop, who help us to fix some problems with hardware

And finally, we would like to thank our families and friends, who supported us while working on the thesis.

Vitaly Tsirkin & Ravil Gazizov

Halmstad University, May 2008

Abstract

A patient lift is used mostly in the hospitals and its main aim is to help nurses to carry patients from one place to another. Today these patient lifts are equipped with motors that can lift patient to some height and then pull down. But the weight of patient lift with hanging person is rather big and it is not easy to push it. In order to help nurses to move the patient lift, the wheels can be driven by motors. These motors can be controlled by the nurse with help of a joystick, but wrong movement of nurse's hand can cause collision with a bed or a wall. To avoid collision and make the process of moving the patient lift more robust and natural it is better to combine the human power, which is produced by pushing the patient lift, with the electrical motors on the wheels, which give additional power assistance. The motor-driven patient lift studied here is controlled by velocity feedback. The objective of this thesis is to develop software for the hardware and build a control law, which will help to move the patient lift and will be stable.

The thesis consists of two main parts. The first part includes all experimental setup and developing the software. In this part the drivers for motors and encoders have been written, the input step excitation has been implemented and all preparations for experiments have been done.

The second part includes modelling and control design. In the modelling part all the experiments were carried out, the models were chosen and the parameters for these models were calculated. Two models have been made because of changed behaviour of the patient lift with and without additional weight. In the control design part the RST controller (R,S,T are characteristic polynomials of the controller, described in chapter 3) was chosen, implemented, downloaded into the control board, the parameters for this controller were calculated and then the control law was tested on the PC and in reality.

The thesis resulted in patient lift with motors, which is controlled by RST controller, which gives very good system that is robust and insensitive to noise.

Contents

1 Introduction

There are a lot of patients in the hospitals, who cannot move themselves because of different reasons. To make procedures for them, which are usually in another room, nurses should lift them up from a bed and move them to a wheelchair. Nowadays nurses usually do these operations with the help of special patient lifts.

The patient passive floor lifts are designed to assist residents with less mobility and can be used on either side of the bed. The adjustable chassis width makes it possible for the chassis to negotiate any obstacles under the bed, which keeps manoeuvring space to a minimum [1].

Today these patient lifts are equipped with motors that can lift a patient to some height and then pull down. But the weight of a patient lift with a hanging person is rather big and it is not easy to push it. Of course, nurses do not need to push the patient lift in the corridor for a long distance; they just need to manoeuvre it between a bed and wall. One of the most difficult things for them is to start moving the patient lift or to change the direction of moving while manoeuvring in the room.

1.1 Patient passive floor lift ARJO «Maxi Move»

The mostly widespread type of patient lifts in Swedish hospitals is ARJO «Maxi Move». The appearance is shown in *Fig. 1-1*. Its weight is 64 kg and it can lift a person with the maximum weight 228 kg. If an average weight of a person is equal to 80 kg, after summation with the weight of patient lift the result will be 144 kg. This weight is not easy to push for a woman, so a way to help nurses should be found. One approach that would help nurses to push a patient lift is to equip it with motors on the wheels. These motors could be controlled by the nurse with help of a joystick, but wrong movement of the nurse’s hand can cause collision with a bed, wall or even worse run over her feet. To avoid collision and make the process of moving the patient lift more robust it is better to combine the power of motors with the human power.

Figure 1-1. Patient lift

1.2 Objective

Today there are no patient lifts with motors that combine the human power, which is produced by pushing the patient lift, with electrical motors on the wheels, which are powered by patient lift’s accumulator.

The idea to combine the human power with the power of the electric motors was proposed in the Master thesis in [2]. In this work a wheelchair was proposed that relied on feedback from the wheels' velocity measured with encoders. The authors implemented a proportional derivative controller, which made the system robust and insensitive to measurement noise.

The objective of this project is to make a patient lift more easy-to-move by introducing power assistance. That is achieved by using two motors on the wheels in aggregate with control board and velocity feedback.

The hardware part of the patient lift's control system, which includes encoders, controller board, motors, gearboxes, power supply, has been assembled previously.

The main goals of this project are to develop drivers for the hardware and build a control law, which will help to move the patient lift and will be stable. The main idea of the implemented control law is that it only helps to start moving, but does not speed up patient lift to high speed.

1.3 Strategy

The project is divided into 2 main parts: preparing & experimental part and modelling & design.

1.3.1 Preparing & experiments

To carry out experiments, the software for controller will be developed, debugged and downloaded to the controller board. Different step pulses will be generated to simulate the force of pushing the patient lift to get experimental data used for modelling. By connecting a serial cable between PC and the control board, data from both encoders can be transferred directly to Matlab for analysis.

1.3.2 Modelling & design

After «preparing & experiments» part the huge amount of different data will be received. All the collected data will be analyzed; an appropriate model will be built and described as a difference equation.

In the design part the control law will be developed, programmed and tested. The stability criteria for the control design will be investigated. Then the control law with the model of a plant will be simulated on the personal computer. Later it will be loaded in the controller of patient lift and tested in reality. After all these steps, the results of testing the patient lift in reality will be compared with the results from simulations.

2 Experimental setup

At the start was the patient lift ARJO «Maxi Move» with an existing prototype power supply system mounted on it, shown in *Fig. 2-1*. It consists of motors (*Fig. 2-2*), gearboxes (*Fig. 2-3*), encoders (*Fig. 2-4*), power supply blocks (*Fig. 2-5*) and controller board (*Fig. 2-6*). The system is powered from an accumulator. These elements form a closed-loop control system.

Figure 2-1. Patient lift

Figure 2-2. Motor

2.1 Motors

Motors (shown in *Fig. 2-2*) that were used in prototype are Dunkermotoren DC-motors GR 63x55 [4]. They get voltage from power supply blocks and drive the wheels.

2.2 Gearbox

The motors are connected to wheels by Dunkermotoren worm gearboxes SGF 120 [4], which are shown in *Fig. 2-3*. Torque is transmitted from motor through gearbox and transmission belt to wheels.

Figure 2-3. Gearbox

2.3 Encoders

The encoders used are Pepperl+Fuchs incremental rotary encoders RVI58N-series [5]. These encoders (shown in *Fig. 2-4*) with RS-422 interface are directly connected to motor shaft and allow getting changes of the motor's shaft position. Consequently encoder positions will be differenced to get velocity information used as feedback signal.

Figure 2-4. Encoder

2.4 Power supply block

To supply motors with power Maxonmotor 4-Q-DC ADS 50/10 servoamplifiers [6] were used (*Fig. 2-5*). They can operate in such modes: encoder speed control, DC tacho speed control and current control. Here they are used as power supply blocks that produce voltage to motors corresponding to control signal incoming from controller.

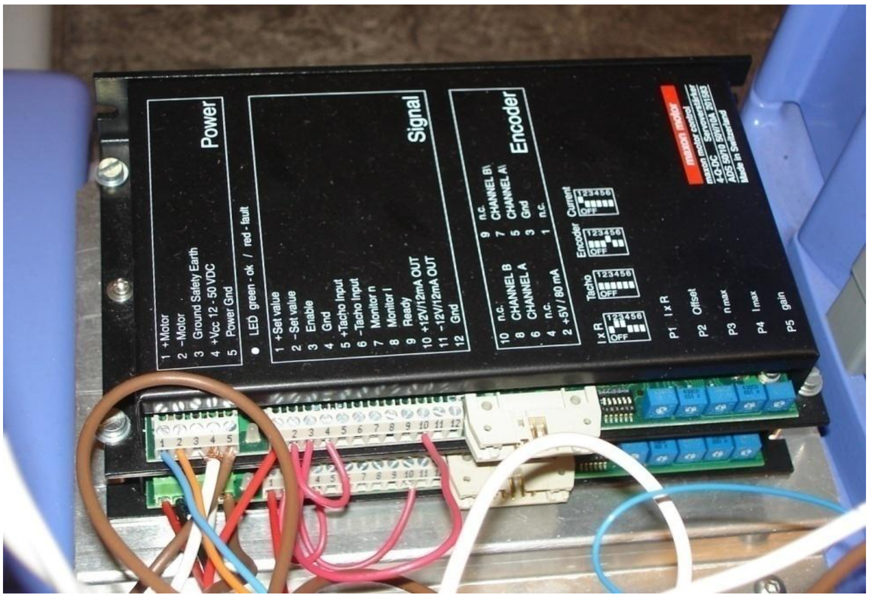


Figure 2-5. Power supply block

2.5 Control board

Central processor, DACs and all interfaces are mounted on the control board, which are shown in *Fig. 2-6*. This board was developed at Halmstad University by Jonas Johansson and Daniel Petersson in cooperation with Tommy Salomonsson.

Microchip Technology PIC18F4525 acts as central processor. It is a 40 MHz 16-bit processor with in-circuit serial programming technology which allows real-time debugging.

LS7266R1 is an encoder to microprocessor interface chip with two 24-bit counters. This chip transmits data from encoders through separate channels, stores it and sends to central processor on demand. This chip gets data from encoders independently from central processor, so the encoders' value can be read at any time.

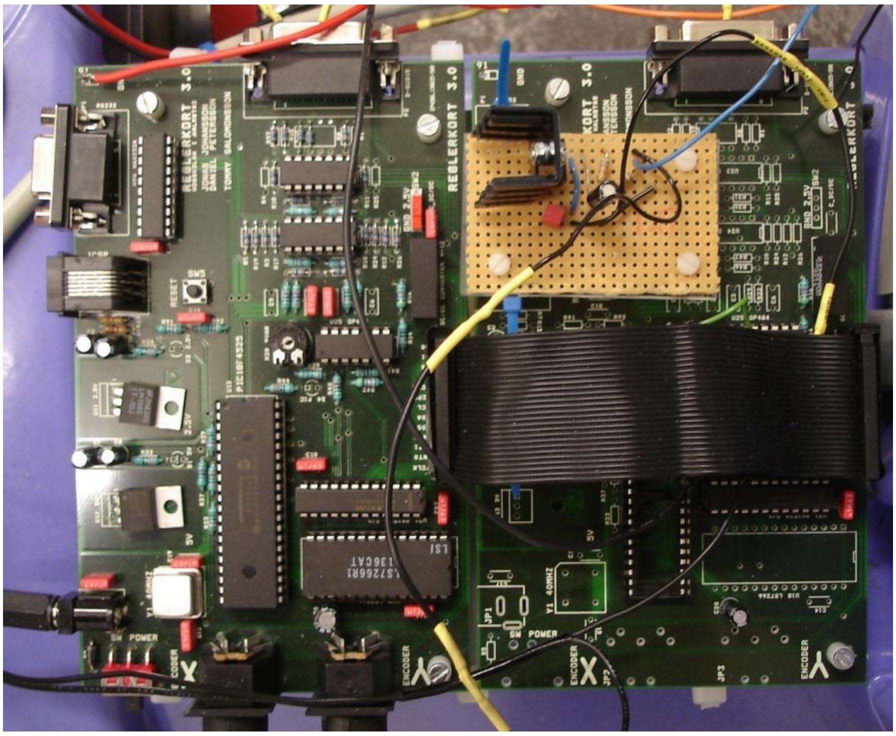


Figure 2-6. Control board

Maxim MAX530BCNG is 12-bit DAC chip which converts digital control signal incoming from controller to analog from 0 to up to 4.096 V. Before transmitting to power supply block it amplifies and rearranges to -10 V … +10 V interval.

Control board is equipped by serial communication interface RS-232 to allow connection to computer. Interface chip is Maxim MAX233A.

2.6 Control system

The control system of patient lift (*Fig. 2-7*) consists of: encoders, which transform the position into code (which will be used to calculate the velocity – feedback signal), which is delivered to controller; controller, which produces control signals to the motors; motors on wheels that move the lift. The system adds motors torque to the pushing force.

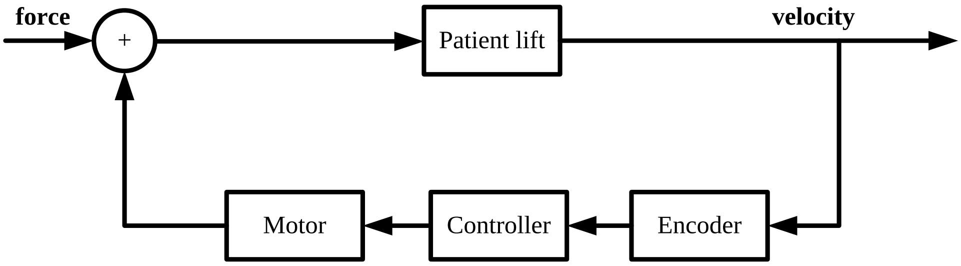


Figure 2-7. Control system of patient lift

2.7 Software

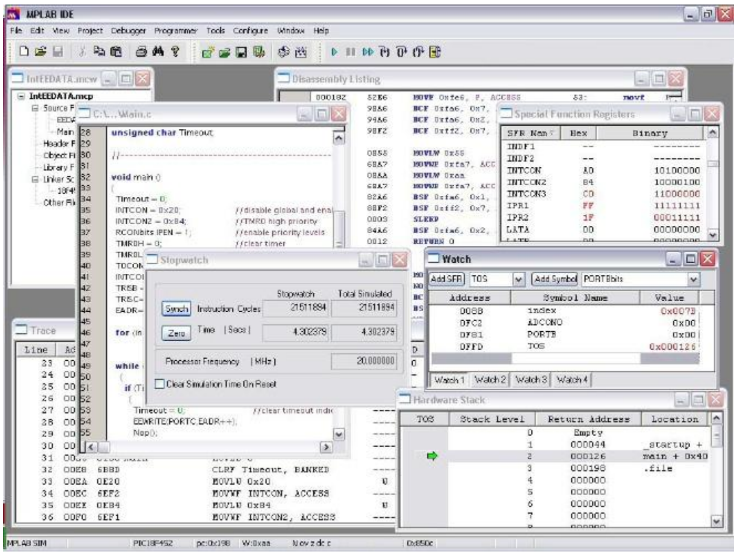
Special software, which is based on Tommy Salomonsson's C-code, was developed to combine all parts into a system. Also new software was written, such as drivers for encoders and motors, because experiments cannot be carried out without them. To get pulse responses of the system rectangular pulse code was written. Pulse length and magnitude set up via computer graphical user interface (GUI, shown in *Fig. 2-10*). Additional variables such as pulse length and pulse magnitude were introduced. To get data from the control board synchronization between input and output variables should be provided; this synchronization was obtained by introducing pause before input pulse.

2.8 Communication

Communication with the system while investigating was supported by RS-interface; while debugging in-circuit debugger MPLAB ICD 2 was used (*Fig. 2-8*) [7]. It is a real-time debugger and programmer for the selected PIC. Using Microchip Technology's proprietary In-Circuit Debug functions, programs can be downloaded, executed in real time and examined in detail with the debug functions of MPLAB. MPLAB ICD 2 requires minimal design guidelines be followed to ensure stable communications between the unit and the target. The MPLAB ICD 2 connects using USB between the design engineer's PC operating with MPLAB IDE and the control board being developed. The program can be single-stepped or run at full speed. At breakpoints, data and program memory can be read and modified.

Figure 2-8. MPLAB ICD 2

To work with system the laboratory was equipped with computer, applications: Mathworks MatLab, Microchip MPLAB IDE (*Fig. 2-9*), and GUI, developed at Halmstad University.



```
unsigned char Timeout;

//------------------------------

void main ()
{
 Timeout = 0;
 INTCON = 0x20;          //disable global and ena
 INTCON2 = 0x84;         //TMR0 high priority
 RCONbits.IPEN = 1;      //enable priority levels
 TMR0H = 0;              //clear timer
 TMR0L
 T0CON
 INTCO
 TRISB -
 TRISC-
 EADR-

 for (in


 while
 {
  if (Ti
  {
   Timeout = 0;          //clear timeout indic
   EEWRITE(PORTC,EADR++);
   Nop();
```

```
000182  52E6  MOVF Oxfe6, F, ACCESS        53:  movf
        98A6  BCF 0xfa6, 0x7,
        94A6  BCF 0xfa6, 0x2,
        98F2  BCF 0xff2, 0x7,

        0E55  MOVLW 0x55
        6EA7  MOVWF 0xfa7, ACC
        0EAA  MOVLW 0xaa
        6EA7  MOVWF 0xfa7, ACC
        82A6  BSF 0xfa6, 0x1,
        8EF2  BSF 0xff2, 0x7,
        0003  SLEEP
        84A6  BSF 0xfa6, 0x2,
        0012  RETURN 0
```

	Stopwatch	Total Simulated
Instruction Cycles	21511894	21511894
Time (Secs)	4.302379	4.302379
Processor Frequency (MHz)		20.000000

☐ Clear Simulation Time On Reset

SFR Name	Hex	Binary
INDF1	--	--------
INDF2	--	--------
INTCON	A0	10100000
INTCON2	84	10000100
INTCON3	C0	11000000
IPR1	FF	11111111
IPR2	1F	00011111
LATA	00	00000000

Add SFR: TOS; Add Symbol: PORTBbits

Address	Symbol Name	Value
008B	index	0x007B
0FC2	ADCON0	0x00
0F81	PORTB	0x00
0FFD	TOS	0x000126

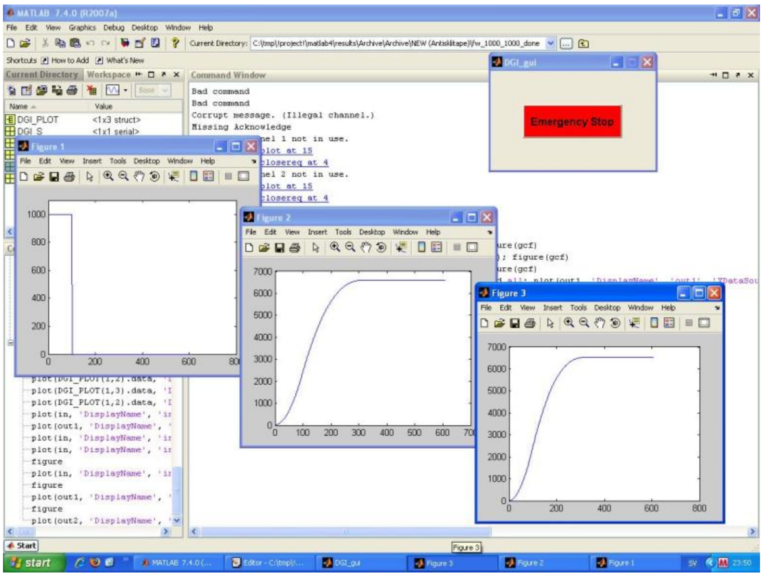
Line	Ad			
32	00E8	6BBD	CLRF Timeout, BANKED	----
33	00EA	0E20	MOVLW 0x20	U
34	00EC	6EF2	MOVWF INTCON, ACCESS	----
35	00EE	0E84	MOVLW 0x84	U
36	00F0	6EF1	MOVWF INTCON2, ACCESS	----

TOS	Stack Level	Return Address	Location
	0	Empty	
	1	000044	_startup +
➡	2	000126	main + 0x40
	3	000198	.file
	4	000000	
	5	000000	
	6	000000	
	7	000000	

Figure 2-9. Microchip MPLAB IDE

MPLAB is an integrated toolset for the development of embedded applications employing Microchip's PIC microcontrollers [7]. MPLAB IDE runs as a 32-bit application on MS Windows, includes a host of software components for fast application development and super-charged debugging.

GUI (*Fig. 2-10*) is a set of program modules in MATLAB that allows getting and setting any variable in the control system and to output data-flow in real time. MPLAB IDE was used as development and debugging application.



```
Bad command
Bad command
Corrupt message. (Illegal channel.)
Missing Acknowledge
nel 1 not in use.
plot at 15
closereq at 4
nel 2 not in use.
plot at 15
closereq at 4
```

```
ure(gcf)
); figure(gcf)
ure(gcf)
```

```
plot(DGI_PLOT(1,3).data, 'I
plot(DGI_PLOT(1,2).data, 'I
plot(in, 'DisplayName', 'ir
plot(out1, 'DisplayName', '
plot(in, 'DisplayName', 'ir
plot(in, 'DisplayName', 'ir
figure
plot(in, 'DisplayName', 'ir
figure
plot(out1, 'DisplayName', '
figure
plot(out2, 'DisplayName', '
```

Figure 2-10. Graphical user interface

3 Methods

The theoretical basics of this thesis include 2 main directions: modelling part and control design part.

3.1 Experimental design

Before starting developing a control law, a good, reliable and adequate model of a plant should be built. The best method to find out all the dynamic characteristics of patient lift is to input a pulse and to look what kind of response will be on the output. The schematic view of experiment is shown in *Fig. 3-1*.

Figure 3-1. Schematic view of experiment

The pulse is characterized by 2 main parameters that can be varied during the experiment: length and amplitude, which are shown in *Fig. 3-2*. Further (in chapter 4), the amplitude will be set in abstract units (0 is equal to 0V, 2047 is equal to 10V).

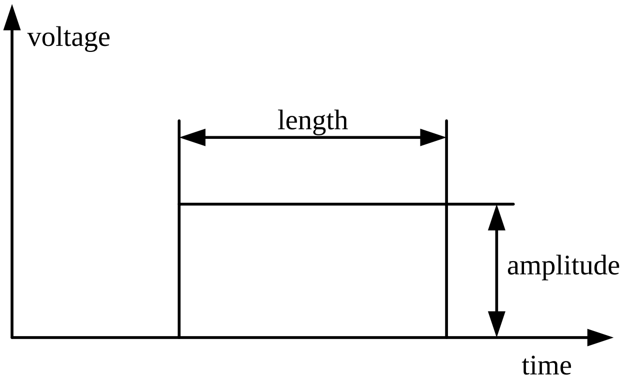


Figure 3-2. Input step pulse

The output response characterizes the dynamics of the plant and is shown in *Fig. 3-3*.

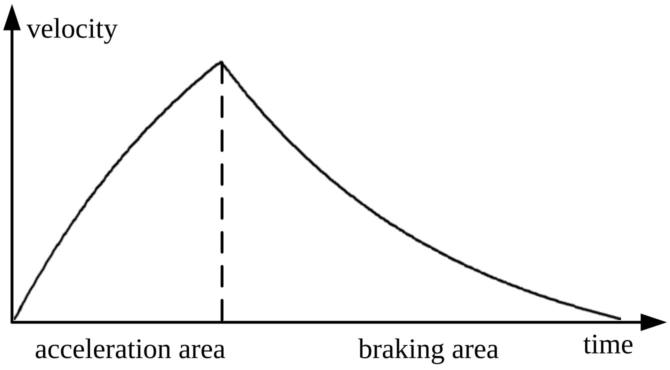


Figure 3-3. Output response

All experiments will be hold in Halmstad University in the laboratory on F5.

During real operation the output signal from the both encoders will be measured; and the push of the patient lift will be the input signal. However since that input signal should be known, the patient lift cannot be just pushed. To make the input signal determined instead of the pushing of patient lift an input signal will be generated directly to motors. This input signal is the step pulse which is described above.

The pulse is generated by the controller according to the introduced parameters. These parameters (amplitude and length of the step pulse) are sent to the controller using GUI. To generate the step pulse by the controller, special software was developed, debugged and loaded into the control board.

To collect the data the control board will be connected to the PC with launched GUI via serial communication interface.

During the experiments the synchronized data from both encoders and at the same time also input signal will be received, so 3 (of 4) parallel channels will be used. The data from encoders will be received in the relative coordinates, but in ability to work with the velocity signal these data should be transformed into the velocity data by differentiating. Each experiment will be made several times in both directions.

The minimum sampling period will be equal to 10 milliseconds because of the traffic-carrying capacity of the serial communication interface and computational power of the PC.

3.2 Modelling

To research the plant a large variety of experiments with different amplitude and length of an input pulse is needed. General form of the difference equation that describes the model is shown below.

$$y(k) = -a_1 y(k-1) - \ \dots a_n y(k-n) + b_0 u(k) + b_1 u(k-1) + \ \dots$$

where, y(k) – k-th output response of the plant, u(k) – k-th input step pulse, a_i, $i = 1 \dots n$, b_j, $j = 0,1,2,\dots$ – parameters of the model of the plant.

The set of parameters θ can be calculated by least-square method (LSM). The model equation that describes plant with error e is shown below.

$$y(k) = -a_1 y(k-1) - \ \dots a_n y(k-n) + b_0 u(k) + b_1 u(k-1) + \ \dots + e(k)$$

Then the parameters of the model will be equal to: $\theta = (\Phi^T \Phi)^{-1} \Phi^T Y$, where:

$$\theta = [a_1 \dots a_n, b_0, b_1, b_2 \dots]^T$$

$$\Phi(\mathrm{k}) = \begin{bmatrix} -y(k-1) & -y(k-n) & u(k) & \dots \\ \vdots & \vdots & \vdots & \vdots \\ -y(N-1) & -y(N-n) & u(N) & \dots \end{bmatrix}; \mathrm{Y} = \begin{bmatrix} y(k) \\ \vdots \\ y(N) \end{bmatrix}.$$

Firstly the model of the patient lift will be the simplest model, which equation is shown below.

$$y(k) = \lambda y(k-1) + bu(k-1)$$

The parameters will be calculated using LSM. If this simplest model would not fit the plant data, then a model with increasing complexity will be investigated.

3.3 Control design

In this section the general structure of the controller will be described and also the way how to calculate the controller parameters will be shown.

3.3.1 General structure

Since a patient lift can be considered as a continuous system, the control system for the plant can be as shown in *Fig. 3-4*.

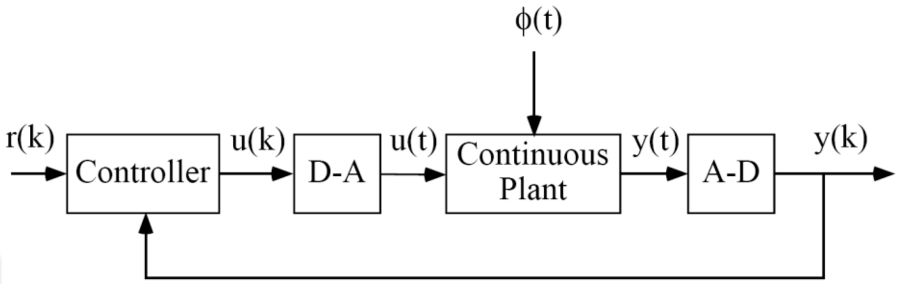


Figure 3-4. Control of continuous time system

In *Fig. 3-4*: r(k) – reference signal, u(k) – discrete time control signal, u(t) – continuous time control signal, ϕ(t) – disturbance, y(k) – discrete time output response, y(t) – continuous time output response.

From the controller's viewpoint a continuous-time plant extended with digital-to-analog (D-A) and analog-to-digital (A-D) converters, as in *Fig. 3-4*, is also a discrete-time system. A model-based controller design can therefore use a discrete-time representation of the plant even though the physical plant is continuous. In *Fig. 3-5* the plant as well as the controller are discrete-time systems [8].

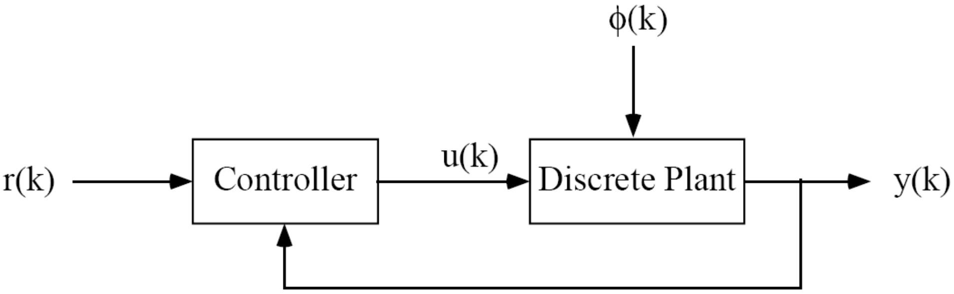


Figure 3-5. Control of discrete time system

According to the objective of the thesis to build a control law the control system could be as shown below in *Fig. 3-6*. The polynomial B/A is a model of the patient lift, and polynomial –S/R characterizes the controller that should change the output response of the closed-loop system as shown in *Fig. 3-7*.

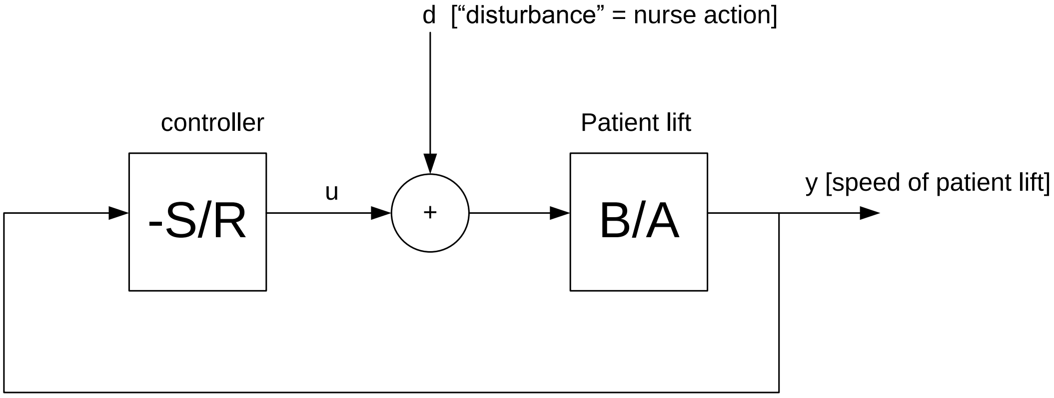


Figure 3-6. Proposed control system

The polynomials: $A(q^{-1})$, $B(q^{-1})$, $R(q^{-1})$, $S(q^{-1})$ are described below.

$$A(q^{-1}) = 1 + a_1 q^{-1} + \dots + a_{degA}\, q^{-degA}$$

$$B(q^{-1}) = b_1 q^{-1} + \dots + b_{degB}\, q^{-degB}$$

$$R(q^{-1}) = 1 + r_1 q^{-1} + \dots + b_{degR}\, q^{-degR}$$

$$S(q^{-1}) = s_0 + s_1 q^{-1} + \dots + b_{degS}\, q^{-degS}$$

The main idea of controlling the patient lift (*Fig. 3-7*) is to lift up the output response curve (velocity, ‘y’) as fast as possible to help the nurse at the start of moving, and then move this curve down also as fast as possible to prevent the system from becoming unstable and not to allow the system speed up too much.

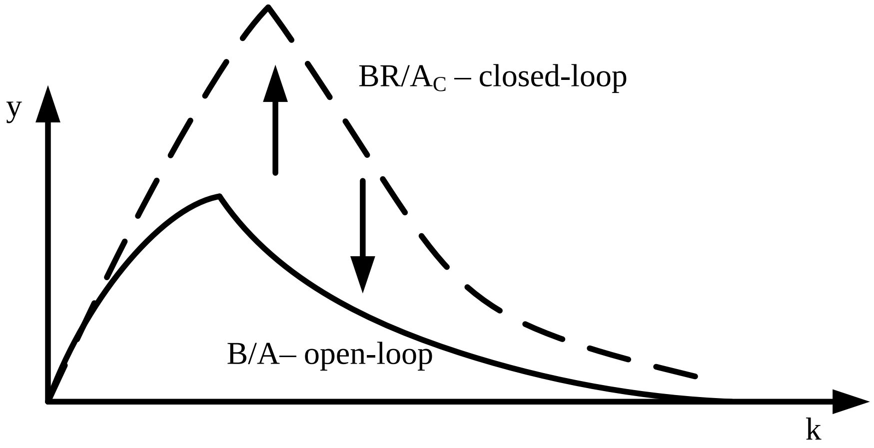


Figure 3-7. Open and closed loop responses, where $\mathbf{A_C = AR + BS}$

3.3.2 Proposed structure

After the general structure and the model of the patient lift is known (assume that the simplest model, described in chapter 3.1, is reliable and adequate), the type of controller satisfying all requirements to the closed-loop system, described in chapter 3.3.1, should be chosen.

The equation for the model of the plant is shown below, where y is the velocity of the patient lift and d is the disturbance – the force of the nurse while pushing.

$$y(k) = \lambda_0 y(k-1) + \ b_1 d(k-1)$$

The system is stable, so $0 < \lambda_0 < 1$

Using the backward-shift operator ($q^{-1} y(k) = y(k\text{-}1)$) the system is described as shown below.

$$y(k) = \frac{B(q^{-1})}{A(q^{-1})} d(k); \qquad \begin{cases} B(q^{-1}) = b_1 q^{-1} \\ A(q^{-1}) = 1 - \lambda_0 q^{-1} \end{cases}$$

The controller should turn on the motors to add additional power to the push, and the feedback signal for it is the velocity of the patient lift. Assume that the additional power from the motors u is given in the same way as that obtained (d) when nurse pushes the lift, so the equation, which describes the system, can be written:

$$y = \frac{B}{A}(d + u);$$

Proportional control design

The simplest kind of controller to implement is proportional controller (shown in *Fig.3-8*).

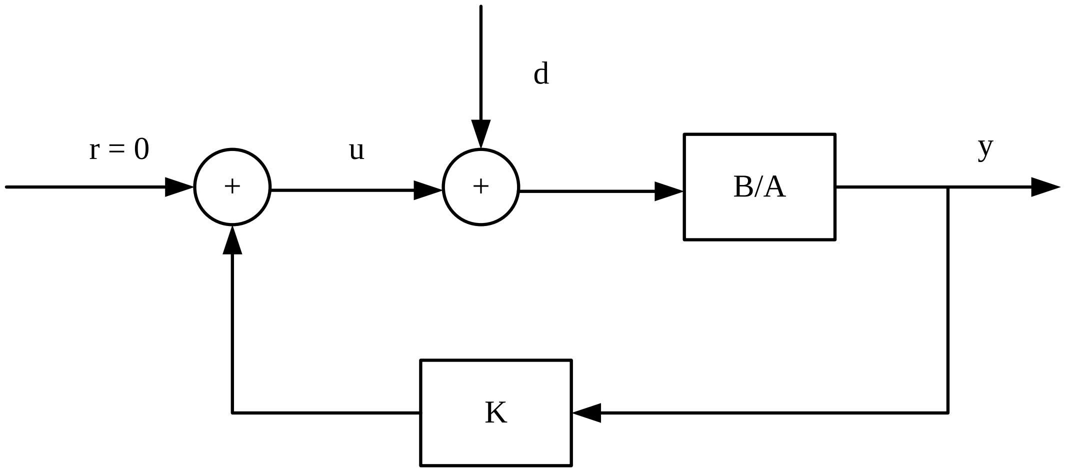


Figure 3-8. The proportional control system

The control signal of P-controller looks like *u(k) = Ky(k)*. If the constant K is chosen negative than the feedback is negative and reduces the disturbance. In the case of this thesis the nurse's force should be amplified, therefore the constant K should be chosen positive. The closed-loop system can be described as shown below.

$$y = \frac{B}{A_C} d,$$

where $A_C = A - BK = 1 - \lambda_1 q^{-1}$. It is a closed-loop characteristic polynomial with the pole $\lambda_1 = \lambda_0 + Kb_1$. Next *Fig. 3-9* shows open-loop and closed-loop responses of the system with P-controller in general.

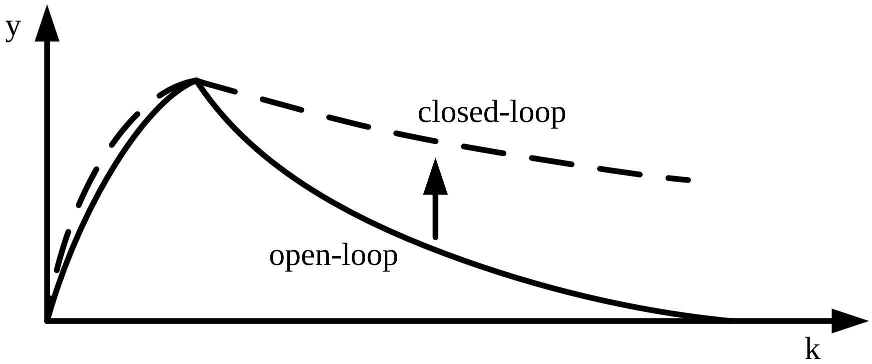


Figure 3-9. Open- and closed-loop responses of the system with P-controller

The positive feedback in this case cannot lift up peak; this feedback can lift the curve of the closed-loop system just after it achieves the peak of the open-loop system. In reality it means that the patient lift cannot accelerate faster, it can only move a longer distance. So for the nurse the use of the P-controller will not make the patient lift easier to move in the beginning and only makes it more difficult to stop. That is why the P-controller does not satisfy the objective of this thesis.

RST control design

To be able to lift up the peak and help a nurse at the start, the RST controller will be implemented. The structure of this controller is shown below.

$$u(k) = -\frac{S(q^{-1})}{R(q^{-1})} y(k); \qquad \begin{cases} S(q^{-1}) = s_0 + s_1 q^{-1} \\ R(q^{-1}) = 1 + r_1 q^{-1} \end{cases}$$

The closed-loop system:

$$y = \frac{RB}{A_C} d,$$

where $A_C = AR + BS$ is the closed-loop characteristic polynomial. Since deg R = deg S = 1, two closed-loop poles can be used in the design. These poles should be also $0 \leq \lambda_k < 1$, $k = 1,2,$ because of the restrictions on stability and damping. The idea is to have an «early peak», which will make easier pushing the lift at the beginning and then have high damping after this peak has been reached. The fast damping is needed to avoid running over the feet of the nurse when pulling the lift. The dynamic of the closed-loop system is:

$$\frac{RB}{A_C} = \frac{b_1 q^{-1}(1 + r_1 q^{-1})}{(1 - \lambda_1 q^{-1})(1 - \lambda_2 q^{-1})}$$

Arbitrary pole placement to get the closed-loop polynomial $A_C = (1 - \lambda_1 q^{-1})(1 - \lambda_2 q^{-1})$ can be obtained by choosing deg S = 1 and deg R = 0 (means that R = 1). From the equation $A_C = AR + BS$, S can be found analytically:

$$S = \frac{(A_C - AR)}{B} = \frac{(a_{c1} - a_1) + a_{c2} q^{-1}}{b_1} = s_0^0 + s_1^0 q^{-1} = S^0$$

where $a_{c1} = -(\lambda_1 + \lambda_2)$ and $a_{c2} = \lambda_1 \lambda_2$. One particular solution to the pole placement equation is $R = R^0 = 1$ and $S = S^0$, where

$$s_0^0 = (\lambda_0 - \lambda_1 - \lambda_2)/b_1$$

$$s_1^0 = \lambda_1 \lambda_2 / b_1$$

To get all the solutions a homogeneous solution is added (to the equation $AR + BS = 0$). This is the Q-parameterization:

$$R = R^0 + QB$$

$$S = S^0 - QA$$

where $Q(q^{-1})$ is an arbitrary polynomial. Choosing Q equal to a scalar K, the polynomials R and S will be: $S(q^{-1}) = s_0 + s_1 q^{-1}$, $R(q^{-1}) = 1 + r_1 q^{-1}$, with parameters:

$$r_1 = K b_1$$

$$s_0 = s_0^0 - K$$

$$s_1 = s_1^0 + K\lambda_0$$

The parameter r_1 can be chosen independently from any chosen pole placement λ_1 and λ_2.

The controller will be implemented as the difference equation:

$$u(k) = -r_1 u(k-1) - s_0 y(k) - s_1 y(k-1)$$

4 Experiments and results

This chapter includes modelling and control design results. In the modelling part the experimental process is described and the final model is made. In the control design part the parameters of the RST controller are calculated and results of simulating and experiments in reality are shown.

4.1 Modelling results

After carrying out first experiments the slipping of wheels when the patient lift starts to move was detected. The patient lift also turns sometimes left and sometimes right while moving. These observations are shown in *Fig. 4-1*.

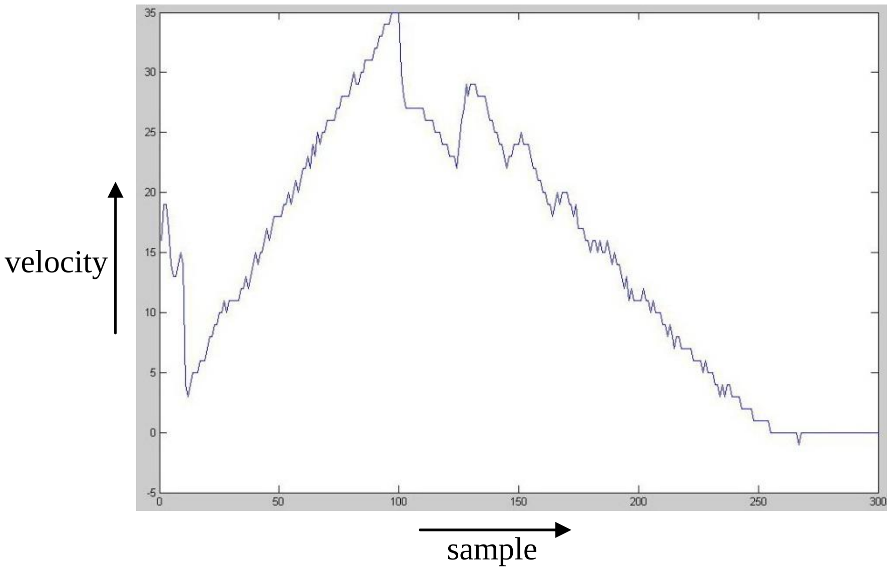


Figure 4-1. Example of the first experiment (data from one of the encoders, sampling period 10 msec)

The spike at the beginning, which is seen in *Fig. 4-1,* shows that the wheels slip at the starting.

To avoid slipping of wheels special abrasive cloth strip was used, which is shown in *Fig. 4-2*. The second problem was the turning of wheels. They turn because the floor in the laboratory was not flat. To avoid turning of the patient lift the initial position of wheels were set straightforward and the part of room with nearly flat surface was chosen.

Figure 4-2. Abrasive cloth strip

After the new part of experiments (on the flat surface with special abrasive cloth strip on the wheels) were carried out, the responses look the same as previously (as in *Fig 4-1*). The form of the response curve is the same; just the spike becomes a little bit smaller. (This result is shown in *Fig. 4-3*)

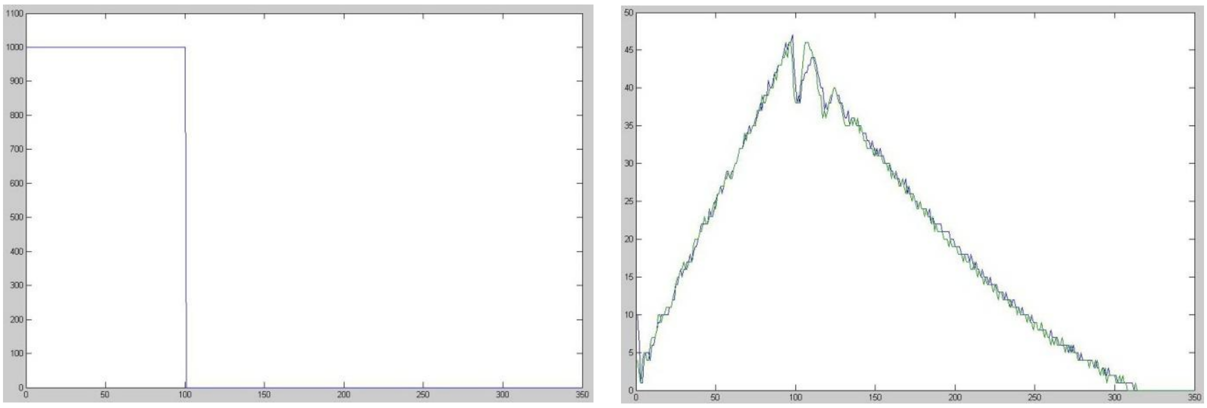


Figure 4-3.
Left: input step impulse with the length 1 second (sampling period 10 msec)
Right: output step response from both encoders

These spikes appear because of the play in the gearbox and belt transmission mechanism. This conclusion was also made in the master thesis in [2]. This play in gearbox cannot be eliminated in the scope of this thesis.

A lot of experiments with different input pulses were made.

The data from experiments in both directions with the same amplitude and pulse length are shown in *Fig. 4-4*. In these plots there are data of 5 experiments and from both encoders.

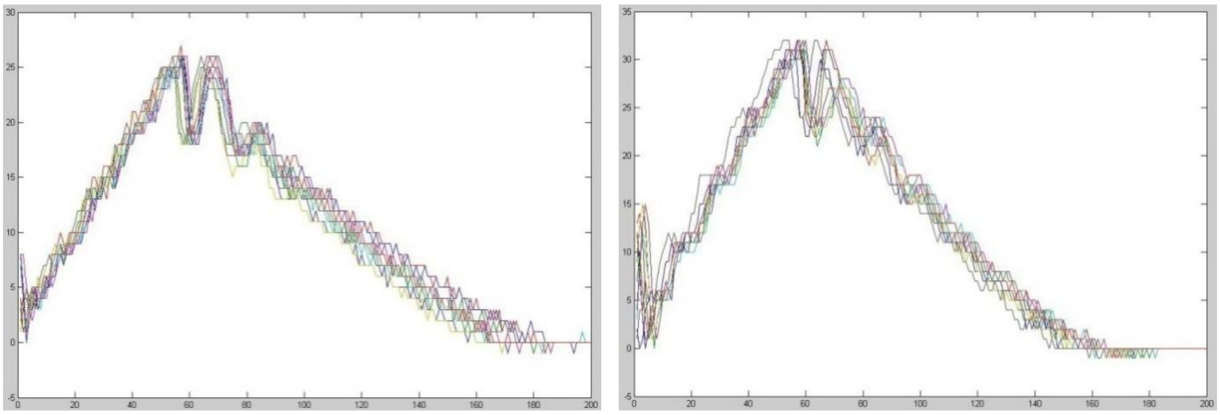


Figure 4-4. Output response for the input pulse with amplitude = 1000, pulse length = 0.6 sec, (sampling period 10 msec). Left: forward (when the nurse pushes the patient lift), right: backward (when the nurse pulls the patient lift).

The curves differ a little bit from experiment to experiment. It happens because the initial positions of front wheels are not exactly the same in each experiment, and the surface of the floor is rough.

After enough data was collected, the building of a model can be started. First, all the data should be analysed. The plot of the data is shown in *Fig. 4-5*.

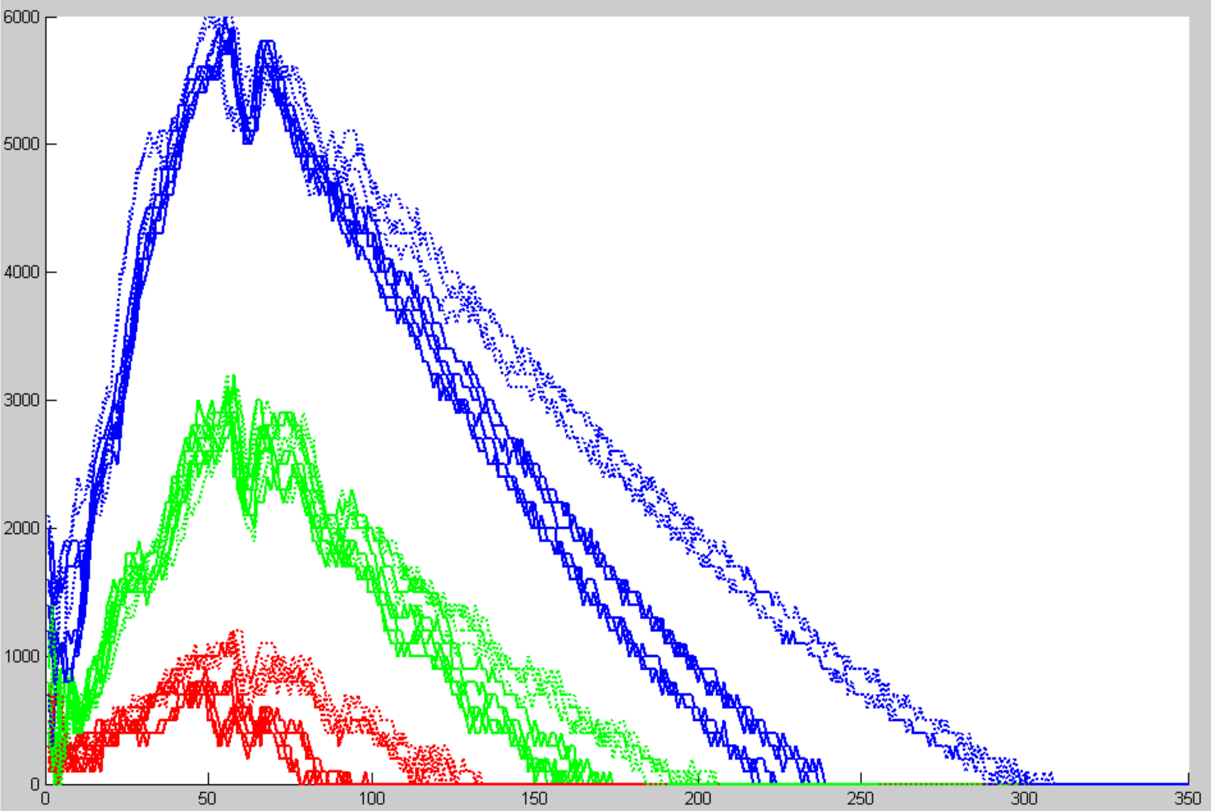
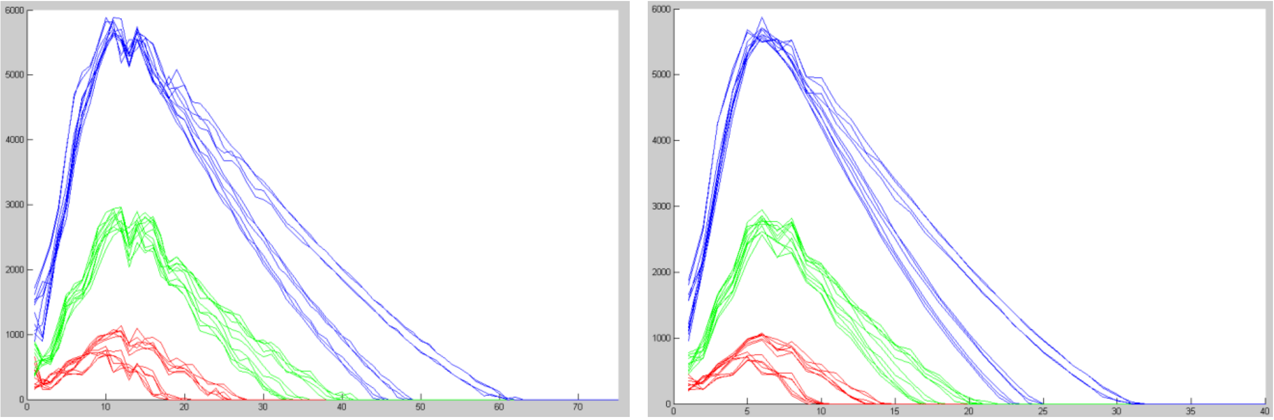


Figure 4-5. Data set (pulse length = 0.6 sec), 6 responses for forward (dot line) and backward (solid line) direction, (sampling period 10 msec)
Red: amplitude = 500, green: amplitude = 1000, blue: amplitude = 2000.

In *Fig. 4-5* there are data of pulses with different amplitudes, but with the same pulse length. The sampling period is 10 msec.

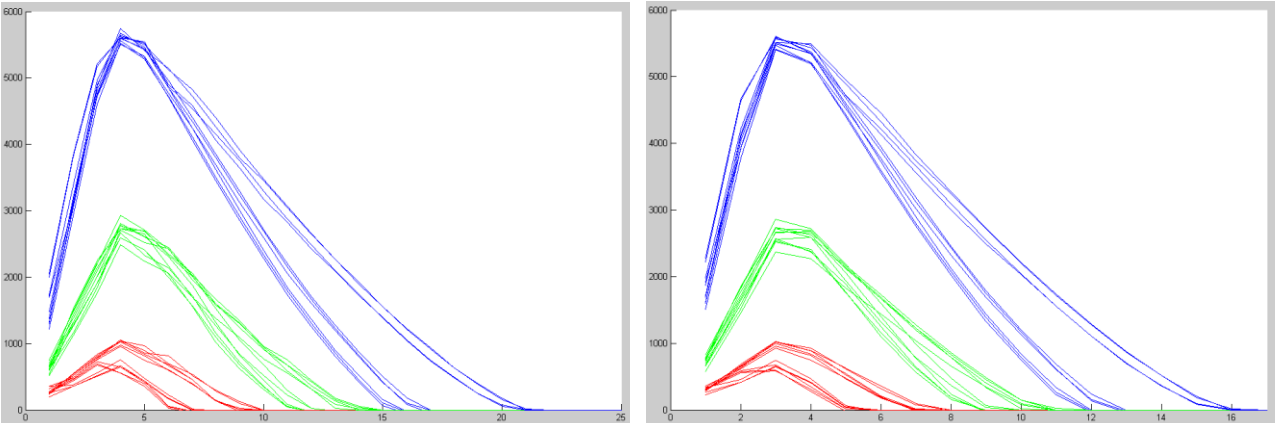
The responses for different directions, but the same input amplitude differ from each other. The patient lift moves a little bit less in the backward direction. The reason could be that, more slip is present when moving backwards since the driving wheels are positioned at the back, which causes less contact forces.

Large oscillations are shown, which probably are due to gearbox dynamics. In order to keep the modelling simple a large sampling period can be chosen to avoid the gearbox dynamics. Different sampling periods are investigated in *Fig 4-6*.



a) 50 msec

b) 100 msec



c) 150 msec

d) 200 msec

Figure 4-6. Data from *Fig. 4-5* with different sampling periods

The curves with less oscillations are in *Fig. 4-6 (d)* with sampling period that is equal to 200 msec. So, the sampling period for the modelling was chosen equal to 200 msec. The slower sampling period will make the control system more robust and insensitive to play in gearboxes, rough floor and other noise.

The model with the simplest structure was chosen, as described in chapter 3.1. The parameters λ and b were estimated by LSM (which is also described in chapter 3.1) and then tuned manually. The results of this tuning are in *Fig. 4-7* ($\lambda = 0.86$; $b = 1.05$).

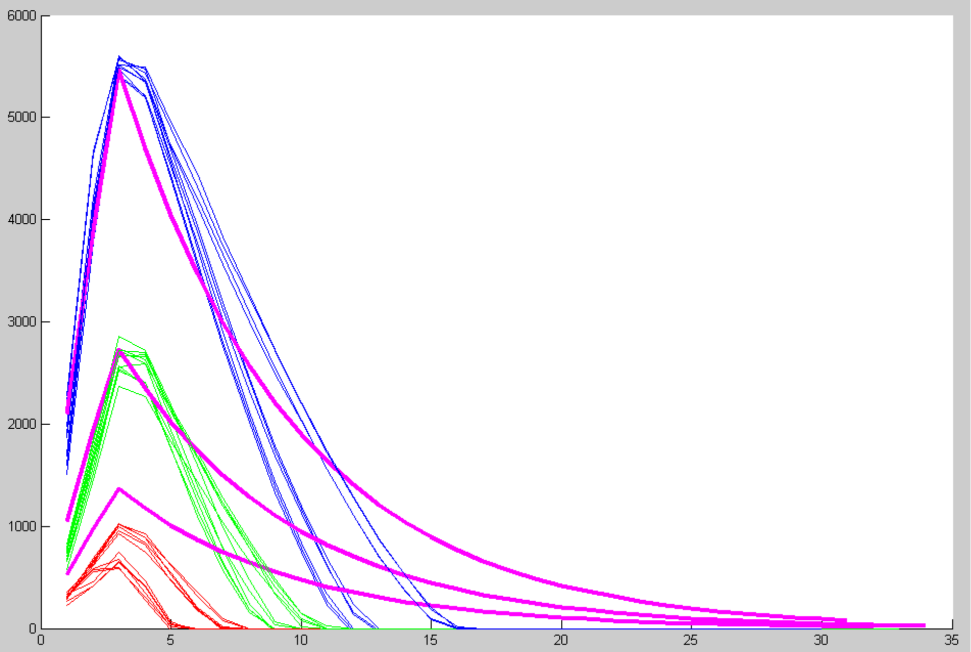


Figure 4-7. The modelling results (magenta) with parameters: λ = 0.86; b = 1.05

The blue set of plots corresponds to the maximum input pulse, which the motors can achieve. The control system should amplify mostly the pulses with smaller amplitude to help the nurse. The blue plots correspond to the maximum response for a control system. So, if a person can push the patient lift with such strength the system will not help him, because of the power limitation of the motors. The blue curves (amplitude = 2000) will be skipped out and the parameters will be tuned again. They should fit red and green curves. The result is seen in *Fig. 4-8* (λ = 0.8; b = 1.2).

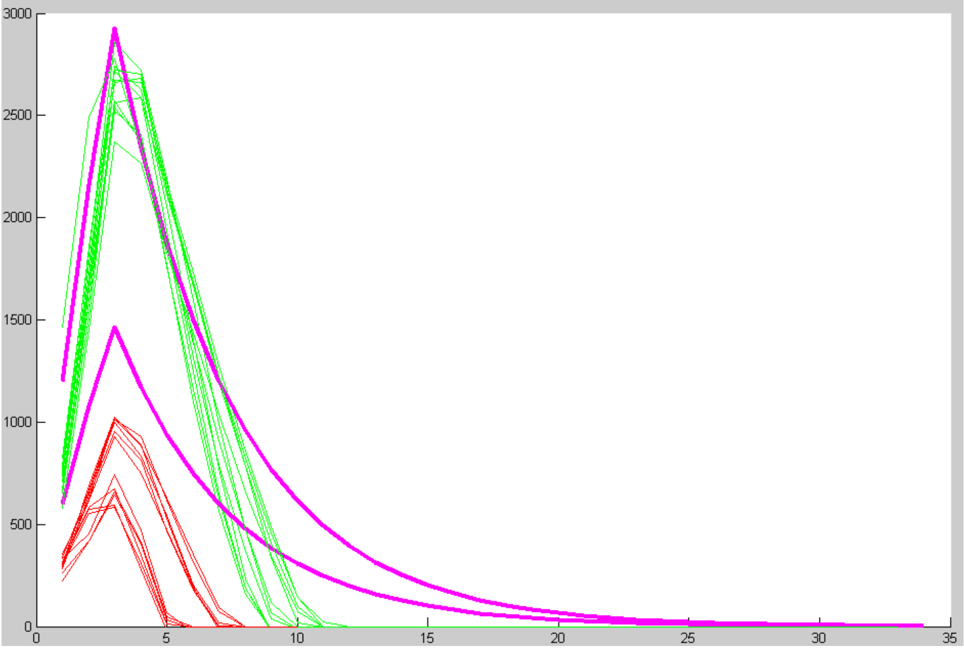


Figure 4-8. The modelling results (magenta) with parameters: λ = 0.8; b = 1.2

The model that will be used in the control design is shown below.

$$y(k) = 0.8y(k-1) + 1.2u(k-1)$$

Patient lift's model with weight

The parameters of the patient lift's model were calculated. But what will happen if somebody will be lifted up? To verify the parameters of the model the new set of experiments were made. The new set is presented in *Fig. 4-9*.

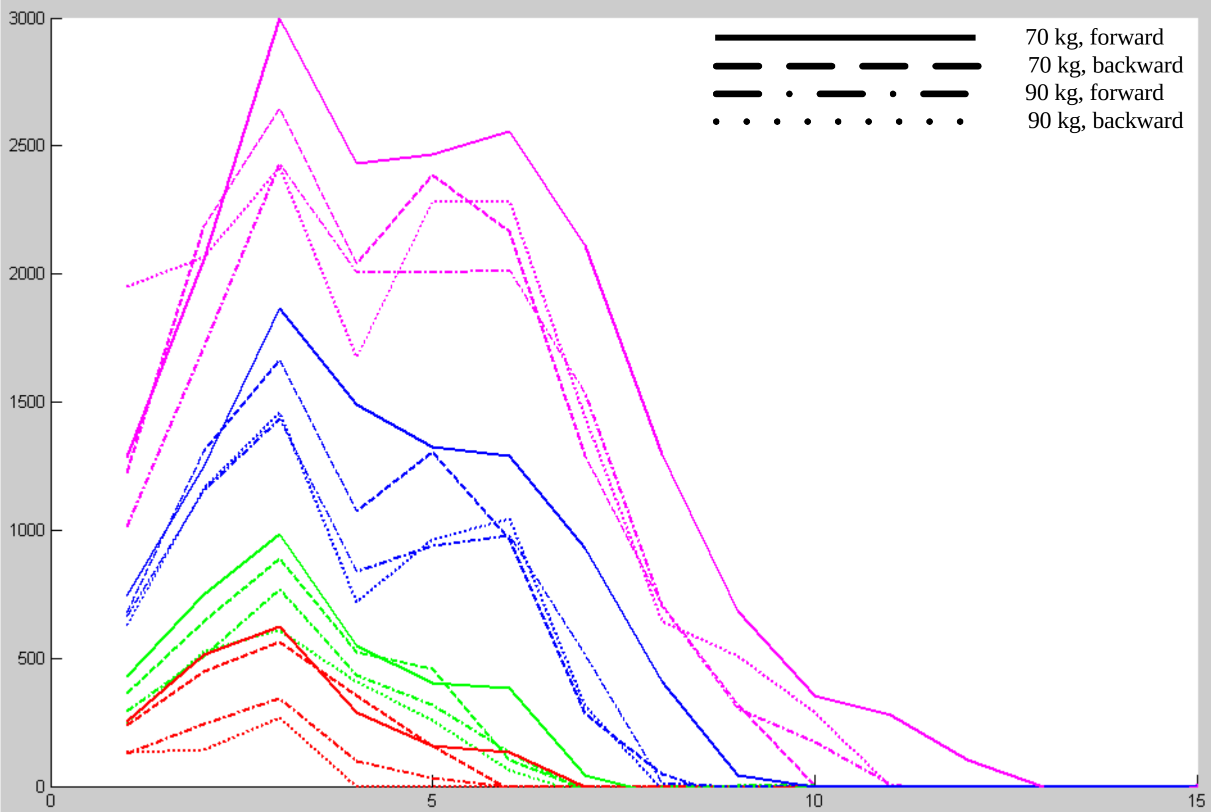


Figure 4-9. Output responses with different weight of a hanging person (70 or 90 kg) for the input pulse with amplitudes: 2000 (Magenta), 1400 (Blue), 1000 (Green), 800 (Red), pulse length = 0.6 sec, backward and forward direction, sampling period = 200 msec.

The new set of experiments was carried out with two persons with different weight. The results with weights 70 and 90 kg do not differ a lot, but both differ much from previous data without additional weight. According to *Fig. 4-9* a patient lift oscillates more than on previous results, especially when the input pulse goes down. It happens because of a hanging person starts to swing. When input pulse goes down, the patient lift starts to brake, and then the swinging person adds some kind of acceleration to the patient lift. The more is the person's weight the more acceleration and oscillations it gives to the patient lift. These oscillations do not matter much and they do not need to be modelled, because in reality the nurse push the patient lift carefully with the continuously increasing force, not like as in step pulse. The previous model does not fit new experimental data; compare *Fig 4-9* to *Fig. 4-5*.

Because of that the experiments with and without additional weight differ much, a model of a plant with some average weight of a person should be built. The average weight of a person was chosen as 70 kg. The model of patient lift with weight will have the same structure as the previous model.

After calculating and manually tuning the parameters, a new model for a patient lift with additional weight was built. It is shown below.

$$y(k) = 0.7y(k-1) + 0.45u(k-1)$$

More detailed the model for the patient lift with additional weight is shown in *Fig. 4-10*.

New model does not fit well the maximum response with the amplitude of input pulse = 2000. But as have been done while modelling the patient lift without weight (and also because of the same reasons), it can be skipped out.

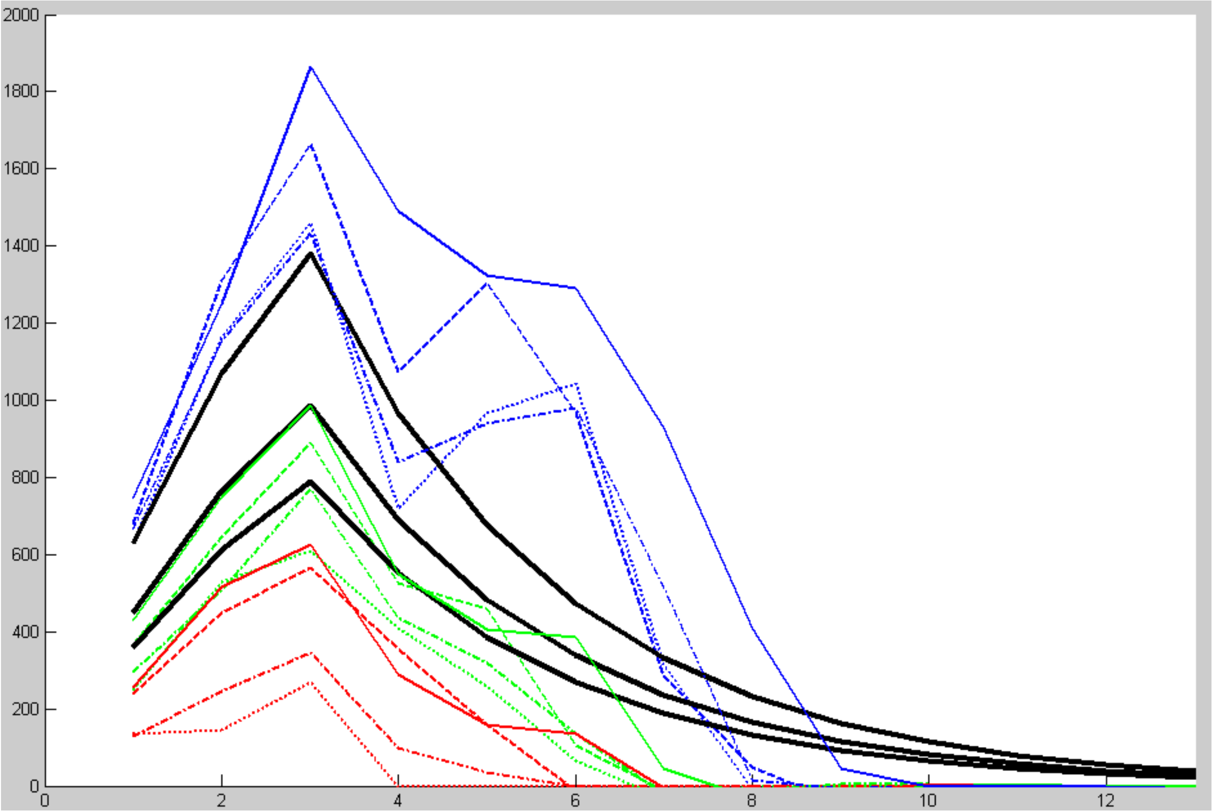


Figure 4-10. The modelling results of the patient lift with additional weight (black) with parameters λ = 0.7; b = 0.45

4.2 Control design results

As described in chapter 3.3 the RST controller was chosen. It was implemented on patient lift.

The RST controller design, which is proposed in chapter 3.3, contains variation of three parameters (in this thesis, in the case of the simplest model, as was developed in chapter 4.1): r_1, s_0, s_1. The transfer function of RST controller is shown in *Fig. 4-11*.

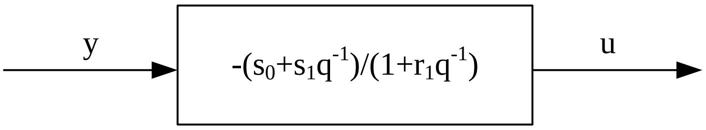


Figure 4-11. RST controller

These three parameters depend on the poles of the closed-loop system and also the value K, which can be chosen freely for any chosen pole placement λ_1 and λ_2. The dynamics of the closed-loop pulse response can be shaped by choosing both the zero and the poles. The restrictions to the closed-loop poles, as was mentioned in chapter 3.3, are $0 \leq \lambda_{1,2} < 1$.

4.2.1 Simulation

The control system with proposed RST controller, which is shown in *Fig. 4-12*, will be simulated. The process will be simulated with two different models (with and without additional weight, which are described in chapter 4.1). In the simulation instead of disturbance *d*, the input step pulse will be used to know the force of disturbance.

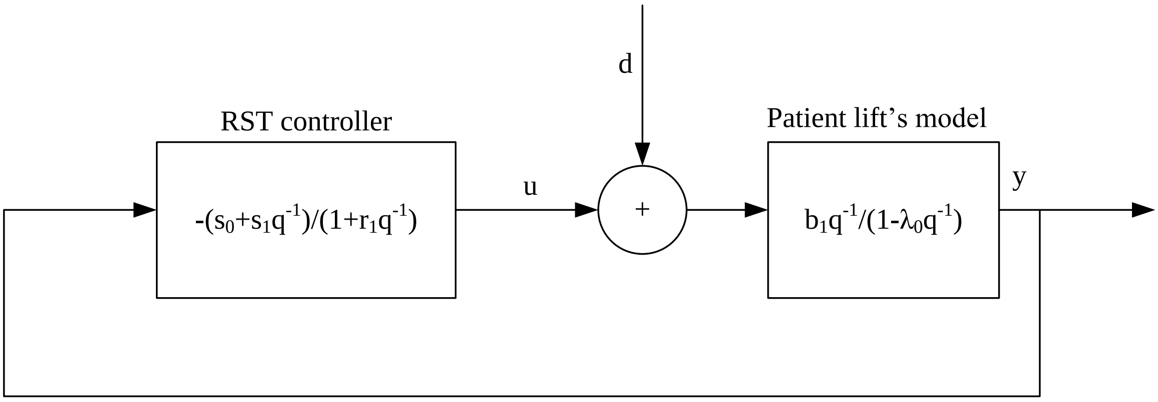


Figure 4-12. The control system of patient lift with RST controller

Simulation of the model without additional weight

The simulated response with parameters of the RST controller: $r_1 = -0.5$, $s_0 = -0.08, s_1 = 0.075$, ($\lambda_1 = 0.7$, $\lambda_2 = 0.7$, K = – 0.42),is shown in *Fig. 4-13*. The input signal has parameters: amplitude = 1000, length of pulse = 600 msec.

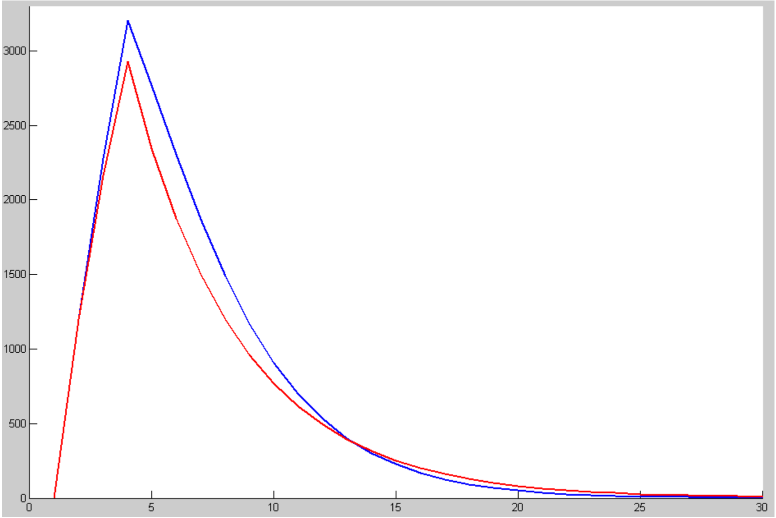


Figure 4-13. Simulated responses
Red: open-loop system, blue: closed-loop system with RST controller

Simulation of the model with additional weight

The simulated response with parameters of the RST controller: $r_1 = -0.65$, $s_0 = -0.11, s_1 = 0.08$, ($\lambda_1 = 0.7$, $\lambda_2 = 0.7$, K = – 1.44), is shown in *Fig. 4-14*. The input signal has parameters: amplitude = 1000, length of pulse = 600 msec.

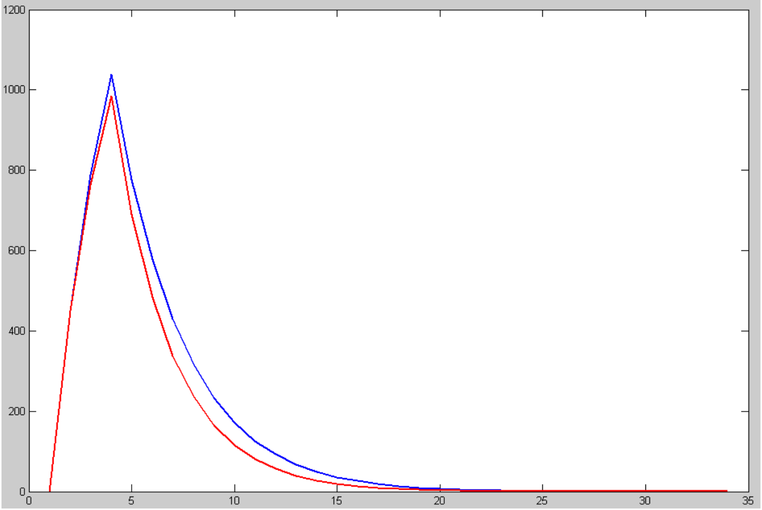


Figure 4-14. Simulated responses
Red: open-loop system, blue: closed-loop system with RST controller

The simulations show that the RST controller can lift up the peak without increasing the lasting time, so it can help to achieve the objective of this project.

4.2.2 Implementation

The RST controller was developed and implemented on the control board of the patient lift. The same disturbance as in chapter 4.2.1 was used. Then the experiments with the controller were made. In *Fig. 4-15* (without additional weight) and *4-16* (with additional weight) there are results of comparing the simulated and measured output responses. The control sampling period is equal to 0.2 sec (5 control signals per second).

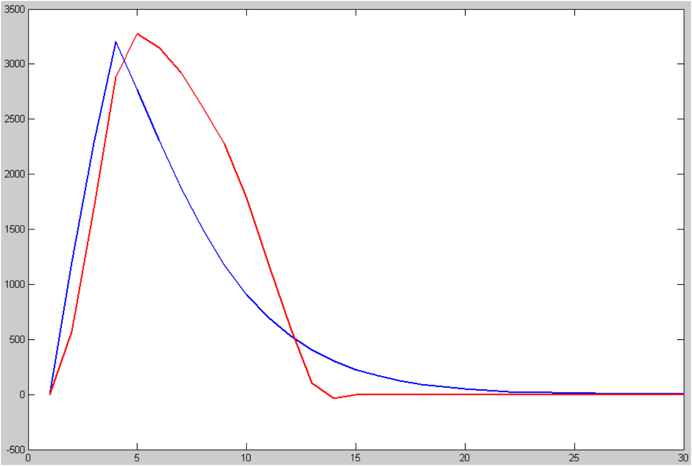


Figure 4-15. Output responses of the closed-loop system with RST controller without additional weight
Red: Measured output response, blue: simulated output response

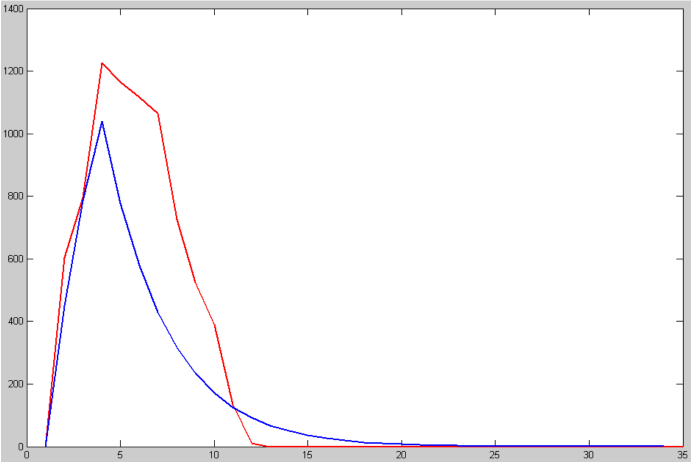


Figure 4-16. Output responses of the closed-loop system with RST controller with additional weight
Red: Measured output response, blue: simulated output response

The mismatch of measured and simulated output response of the closed-loop system with RST controller with additional weight takes place because of the weight of hanging person influences the parameters of the model and consequently the closed-loop system.

4.2.3 Evaluation

The results, which are described in chapter 4.2.2, prove that RST controller satisfies the objective of this thesis and makes the control system that helps nurses to push the patient lift. The parameters of RST controller can be also tuned depending on the weight of the hanging person. These parameters can also tune the size of the «help» by lifting the peak of the output response of the closed-loop system to the different height. Different variants of «help» are shown in *Fig. 4-17*.

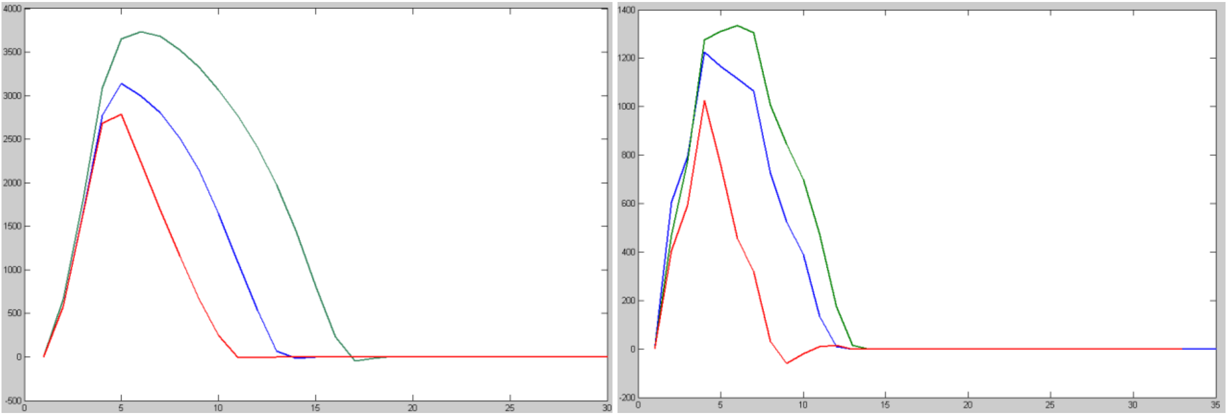


Figure 4-17. Different variants of «help», measured output responses
Left: patient lift without additional weight
Red: open loop system: $\lambda_0 = 0.8$ $b_1 = 1.2$
Blue: closed-loop system: $\lambda_1 = 0.7$ $\lambda_2 = 0.7$, $K = -0.42$
Green: closed-loop system: $\lambda_1 = 0.7$ $\lambda_2 = 0.7$, $K = -0.375$
Right: patient lift with additional weight
Red: open loop system: $\lambda_0 = 0.7$ $b_1 = 0.45$
Blue: closed-loop system: $\lambda_1 = 0.7$ $\lambda_2 = 0.7$, $K = -1.44$
Green: closed-loop system: $\lambda_1 = 0.7$ $\lambda_2 = 0.7$, $K = -1.33$

Curves in *Fig. 4-17* show that the control system really «helps» nurse to push the patient lift. The shape of output response can be defined by setting poles λ_1 and λ_2 of the closed-loop system. Then the size of the «help» can be changed by only one parameter K (increasing of K allows to obtain larger size of the «help»).

5 Conclusions

The objective of this master thesis was to design a control system for a patient lift with motors to make pushing easier. The control system uses velocity as feedback signal. The special software, which includes drivers for the motors and encoders, was written. This software also calculates the velocity from the encoder signal and also compute control signal for RST controller, which is also implemented, debugged and loaded into the control board.

A large part of the thesis was to research, analyze the patient lift and to build an appropriate, good and reliable model. The oscillations of velocity in the experiments can be seen. The oscillations depend on many reasons. The first reason is the play in the gearbox, which cannot be reduced during experiments. The other is that the surface (the floor in the laboratory) is rough. Because of the rough surface the patient lift sometimes turn from straightforward direction. At the beginning of moving the slipping of wheels also happens. The slipping of wheels is the reason of appearing of spikes on the velocity plots, when patient lift starts to move. The choice of sampling period equal to 0.2 second hides these oscillations and spikes. The patient lift moves less in backward than in forward direction. It is because more slip is present when moving backwards since the driving wheels are positioned at the back, which causes less contact forces. The experiments with additional weight (with a hanging person) show that the model of a plant without additional weight does not fit these curves. The patient lift also oscillates more with additional weight, because the hanging person begins to swing after start moving. Because of these reasons two models with different parameters λ and b were calculated, describing the unloaded and loaded situation, respectively.

In the control design part RST controller with two different set of parameters was simulated, implemented and tested. The results of testing the RST controller show that this controller satisfies the objective of this project and makes the control system robust. In spite of the increasing of the output response peak looks small, in reality the «help» of the power assistance system feels good.

The patient lift can be improved further in different ways in the future. For example, the play in gearboxes can by reduced by changing them to better one. The construction of patient lift does not adopted to implement power assistant design as was done in this thesis. It means that when patient is hanging in it, the weight is distributed among back and front wheels unequally. This causes that back wheels, which are driven by motors, lose contact with floor and start to slip, especially in backward direction and turning. This can be improved by installing springs that will always press the wheels to the floor or using some another construction of patient lift. Another example is to equip the patient lift with weight sensor that can detect whether there is a hanging person or not. After detecting the program can automatically switch between 2 controllers with different parameters. Also more experiments with different weights can be made and find out how the model of a plant changes depending on the mass of hanging person. After this more models with different parameters can be made and after detecting the weight of a hanging person the program can switch between models with different parameters. All these improvements make patient lift more comfortable to use, but do not change the main control principals, which were developed and implemented in this thesis.

References

[1] Company. *Arjo.* www.arjo.com (May 2008)

[2] Johansson, J and D. Petersson,
Torque Sensor Free Power Assisted Wheelchair. Master thesis in electrical engineering. Technical report IDE 0703, January 2007

[3] Petersson, D, J. Johansson, U. Holmberg and Björn Åstrand
Torque Sensor Free Power Assisted Wheelchair.
Proceedings of the 2007 IEEE 10th International Conference on Rehabilitation Robotics, June 12-15, Noordwijk, The Netherlands

[4] Company. *Dunker motoren.* Germany, www.dunkermotoren.de (May 2008)

[5] Pepperl-fuchs. *Incremental rotary encoder RVI58N-*******6 Datasheet.* June 4 2007. http://www.pepperl-fuchs.com/selector/navi/productInfo/edb/t14189_eng.pdf

[6] Maxon motor. *4-Q-DC Servoamplifier ADS in module housing*. April 2005, Switzerland. http://test.maxonmotor.com/docsx/Download/catalog_2005/Pdf/05_259_e.pdf

[7] Company. *Microchip.* www.microchip.com (May 2008)

[8] Holmberg, U
Digital control, Halmstad, Sweden, 2005