Recent Advances in Mechatronics
Recent Advances in Mechatronics

With 487 Figures and 40 Tables
Preface

The International Conference MECHATRONICS has progressed considerably over the 15 years of its existence. The seventh in the series is hosted this year at the Faculty of Mechatronics, Warsaw University of Technology, Poland. The subjects covered in the conference are wide-ranging and detailed. Mechatronics is in fact the combination of enabling technologies brought together to reduce complexity through the adaptation of interdisciplinary techniques in production.

The chosen topics for conference include: Nanotechnology, Automatic Control & Robotics, Biomedical Engineering, Design Manufacturing and Testing of MEMS, Metrology, Photonics, Mechatronic Products. The goal of the conference is to bring together experts from different areas to give an overview of the state of the art and to present new research results and prospects of the future development in this interdisciplinary field of mechatronic systems.

The selection of papers for inclusion in this book was based on the recommendations from the preliminary review of abstracts and from the final review of full lengths papers, with both reviews concentrating on originality and quality. Finally, out of 182 papers contributed from over 15 countries, 136 papers are included in this book.

We believe that the book will present the newest applicable information for active researches and engineers and form a basis for further research in the field of mechatronics.

We would like to thank all authors for their contribution for this book.

Ryszard Jablonski
Conference Chairman
Warsaw University of Technology
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Dynamical behaviors of the C axis multibody mass system with the worm gear

J. Křepela (a)*, V. Singule(b)

(a) Brno University of Technology, Faculty of Mechanical Engineering, Technická 2, Brno 616 69, Czech Republic
(b) Brno University of Technology, Faculty of Mechanical Engineering, Technická 2, Brno 616 69, Czech Republic

Abstrakt

This paper describes mathematic model of multibody mass system of the C-axis over mentioned machine. C-axis is controlled with position feedback and its mathematic model is determined for observation of dynamic characteristic in the loadings working cycles before of machine prototype realisation. This multifunction turning centre is determinate for heavy duty roughing cutting of forged peaces, where is problem with dynamic stability of cutting process. Dynamic stability influeces the eigen frequencies the complete torsion system. Positive effect of this conception is for dynamic stability damping on the worm gear.

1. Introduction

Main Spindel of the machine, on the witch is implemented the C axis, is for turning operations driven by asynchronous motor with power 71kW. For high torque moment necessity is gearing reduced through two steps planetary gearbox and constantly belt gear. For milling and drilling operation is this main motor uncoupled through neutral position in this gear box and spindle is hydraulic coupled with worm gears, where are geared with two synchronous servomotors controlled in mode Master – Slave (fig.1.). This mode assures to change the parameters of electrical preloading between both servomotors from the machine control. Preloading of servomotors holds positions of coupling eliminated the production backlash of worm gearing. This is arranged with leaned teeth flanks against both worms opposite teeth of worm gears react in opposite direction of torque moments both servomotors. By this rotating movement is changed step by step the direction of torque moments actuating from contradirection to the same direction, but always continues the constant difference of this moments, which produces
preloading even by rotating.

![Fig. 1. Design of the C axis](image)

Cutting procedure realised many times with more cutting edges tool causes the oscillation of necessary torque moment and it is absolutely necessary to technologically predefine the servomotor preloading value in advance from reason of elimination of contact damaging on the worm gear teeth flank caused from variable loading [3].

2. Multibody system

The simplification is possible just under following condition: The servomotors are connected with worm gears by shafts and they turn them in opposite directions. The turning causes taking up clearances and preload of the worm gear assembly. The construction from the servomotor to the worm gear is turned over an angle $\varphi_M$. The switching-on of the C axis causes the preload and the slewing into a defined angular position. The preload remains constant during machining with the moving C axis and the increase of moments is used just for start up of the servomotors. A torque deviation would lead to a creation of a gap in a tooth space. The spindle remains at the position set up by a CNC control. Please see attached the block diagram of the preloaded mechanical system of the C axis on the figure 2. The interface for multibody mass model is created at the boundry of the parts. The typ of the worm gear is ZA with a gear ratio 40,5. The worm gear was designed as self-locking.
A worm gear holder is taken for simplification as perfectly torsion rigid because its torsion rigidity is multiple higher than the rigidity of the components chained on the worm shaft. It is necessary to calculate a torsional rigidity and a moment of inertia of individual components as well as approximately calculate damping on the worm gear for the mathematical model of the C axis. The torsional rigidity of the spindle and the worm shaft are calculated with the help of the FEM (Finite Element Method). The calculation of contact stiffness on tooth of the worm gear is highly simplified to a 2D model. The contact rigidity is solved in the plane perpendicular to the pitch of tooth of the worm wheel. The model includes the coefficient of the tooth in the grip 2.94 with help of three tooth in the grip. The force creating the deformation at this plane is calculated as the force between two built-in solids of the worm and the worm wheel. The worm wheel is simplification by the fixation of a meshing segment at the position of the interface between the bronze metal and stell holder. The overall stiffness of the chain of the components between the servomotor and the worm gear is necessary to calculate for the definition of the preload torque. A moment of inertia of the component parts is directly detected in the 3D model of the design of the C axis. The coefficient of damping is necessary for the description this mechanical system.

For influence evaluation of eigen mechanical frequencies of the C axis control system is necessary this problem separated to the two situations.
First situation consist of the loading oscilation by the self-locking blockade of the worm gear. This situation has the influence on the direkt measure system of the C axis. Eigen frequency is calculated under equation 1.

\[ f_{rez} = \sqrt{\frac{k_{s+w}}{J_w}} \]  

(1)

Second equated situation consist of multibody system of the parts chain from the servomotor till to the loading. Interface of the blockade is created between the spindel and workpiece. Eigen frequencies by the blocked loading is calculated under equations 2 till 7.

Equation of motion in the matrix form without the damping:

\[ M \ddot{q} + Kq = 0 \]  

(2)

Transfer to the complex plane:

\[ q = \nu e^{j\omega t} \]  

(3)

\[ M^{-1}K\nu = \Omega^2 \nu \]  

(4)

Determinant of left site the equation must be to equal 0 for the solution of the eigen frequencies:

\[ |M^{-1}K - \Omega^2 E| = 0 \]  

(5)

Matrix of mass:

\[
\begin{bmatrix}
J_{sw} & 0 & 0 \\
0 & J_c & 0 \\
0 & 0 & J_m
\end{bmatrix}
\]  

(6)

Matrix of stiffness:

\[
K =
\begin{bmatrix}
 k_{s+w} + k_{sw} & -k_{sw} & 0 \\
-k_{sw} & k_{sw} + k_{c+m} & -k_{c+m} \\
0 & -k_{c+m} & k_{c+m}
\end{bmatrix}
\]  

(7)
3. Manuscript submission

First eigen frequency of the C axis determines the size of the proportional amplification $K_v$. Further eigen frequencies influence the the proces of the responses on the torque steps or dynamic of the run-up. In the table 1. are written values for eigen frequencies.

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<td>2. eigen frequency by the located loading [Hz]</td>
<td>32.3</td>
</tr>
<tr>
<td>3. eigen frequency by the located loading [Hz]</td>
<td>40</td>
</tr>
</tbody>
</table>

Tab 1. Eigen frequency

On the stability by the step changes has advantageous influence the dumping of the worm gear. Big ratio of the worm gear reduces the influence of the moment of inertia of the workpiece on the eigen frequency. The knowledge of the eigen frequencies for this mechanical system enables accurater regulators optimization both motors.

References

Control unit architecture for biped robot

D. Vlachý, P. Zezula, R. Grepl

Institute of Solid Mechanics, Mechatronics and Biomechanics, Faculty of Mechanical Engineering, Brno University of Technology, Czech Republic

Abstract

This paper deals with the design of a control unit for biped robot „Golem 2“ with 12 DOF. It contains information about the topology of electronic system, including description of communication between MC units, sensing elements and PC. The kinematic models used for drive robot and the information about their importance for static walking are mentioned. Some information about actuators (Hitec servos) and specificity their control are also described.

1. Introduction

Design and implementation of autonomous locomotion robots belongs to the important areas of academic as well as commercial research and development. Actually, we are focused on the design of the control unit for biped robot named „Golem 2“, with following features: implemented kinematic models, ready to acquisition sensor data (from Acc, camera, FSR etc.), wireless control of robot and possibility for integration of high level AI algorithms (Image processing and understanding, neural network approximator, agent oriented software etc.).

2. Static walking and importance of kinematic models

Without a kinematic models, we have a few simple methods, how to obtain a elemental static walking, for example setting each servomotor separately to get a one stable position of robot and consequently make a step as a sequence of that positions. This „uninformed methods“ spent much time and results may not be acceptable, because of non system admittance. In
case of advanced non elemental walking, there aren’t simple methods usable and we crave help of kinematic models.

The robot „Golem 2“ [2], developed at Laboratory of mechatronics is comprehended as an open tree manipulator and therefore standard algorithms for forward and inverse kinematics was used to get the appropriate kinematics models. Forward kinematic model (FKM) and Inverse kinematic model (IKM) are described in [1] in details.

By the help of FKM, we can get the position of legs against the body of robot (and reversely) from information about actual servo states. By the help of IKM, we can get the relevant servo states, relativly to desired position of legs. So we can easy define a vector, which means the changes in position of body from the last taken position:

\[
\Delta = \begin{pmatrix}
\Delta x \\
\Delta y \\
\Delta z \\
\Delta \varphi_R \\
\Delta \theta_P \\
\Delta \psi_Y
\end{pmatrix}
\]  \hspace{1cm} (1)

Where \([x, y, z]\) is cartesian position and \([\varphi_R, \theta_P, \psi_Y]\) is spatial orientation of foot in roll–pitch–yaw notation (Euler angles XYZ).

We can now define a sequential moving of robot as a vector:

\[
\text{moving} \approx \begin{pmatrix}
\Delta_1_{l_1} \\
\Delta_2_{l_2} \\
\vdots \\
\Delta_L_{l_L}
\end{pmatrix}
\]  \hspace{1cm} (2)

Where \(l\) is needle, determining target of using \(\Delta\):

\[t \in \{\text{Left, Right, Both}\}\]
This formulation of moving is much better to develop any locomotion, e.g. static walking. This idea is shown in Fig.1.

3. Control unit

Complete control unit consists of several cooperating units – PC, AT Mega 128 „main unit“, AT Mega 8 „servo control unit“, sensor modules. The backbone network is serial line with our original protocol (variable packet size, master-slave architecture), interconnection between main unit and sensor modules run over SPI interface. The topology is shown in Fig.2.

**PC** – The main brain. In PC are implemented both kinematic models (because high hw requirements) and GUI for manipulating robot. PC is connected via bluetooth adapter. Implementation in Delphi, some parts uses outputs from Matlab.

**AT Mega 128 „main unit“** - Keep wireless connection between robot and PC. Interpolate continuous positions for servos in relation to desired speed. Share data form all connected peripherals together. In progress: Data acquisition from Battery, Accelerometers and FSR sensing modul. Communicate with EyeBot controller.

**AT Mega 8 „servo control unit“** - Individually control 12 servos, by signals based on the length of pulse. Hardware peripherals (1x16bit Timer/Counter + 1x8bit Timer/Counter, USART) are exploited and soft-
ware is fully event-driven by the help of interrupts, it’s important to precise servos control. There are 4 types of servos made by Hitec and controlled by the length of pulse, generated every 20ms (50Hz). To get the best results, we have to precise servos control, i.e. find the right mutual characteristic between desired position and final pulse length.

We observed, that the each type of servo used, need itself mutual characteristic that is defined by linear function, and is necessary to find out the right constants for each type of servo. Our control now proceed with precise to 1°, except the 2nd ankle, there is a double precision needed, so the extra mutual characteristic is defined for relevant servos.

Fig. 2. Topology of control unit
**Sensor modules** – These modules administer sensors. Each sensor module has its own microcontroller, communicates with the main unit via SPI and provides appropriate data on demand. Eyebot controller has other usable properties, which we plan to exploit.

5. **Conclusion**

The control unit was designed, successfully tested and a first goal, static walking, was accomplished. The future work will be headed to fully integration of sensors and enhanced static walking (uneven surface, barriers in trajectory etc.). The dynamic walk using complex dynamic model will be the next goal in robot development.

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**References**

Quantifying the amount of spatial and temporal information in video test sequences

A. Ostaszewska, R. Kloda

Warsaw University of Technology, Faculty of Mechatronics, Sw. Andrzeja Boboli 8 Str., Warsaw, 02-525, Poland

Abstract

In case of compressed video quality assessment, the selection of test scenes is an important issue. So far there was only one conception for evaluation the level of scene complication. It was given in International Telecommunication Union recommendations and was broadly used. Authors investigated features of recommended parameters. The paper presents the incompatibility of those parameters with human perception that was discovered and gives a proposal of modification in algorithm, which improves accordance of parameters with observers’ opinion.

1. Introduction

The rapid growth of digital television, DVD editions and video transmission over the Internet has increased the demand for effective image compression techniques and the methods of coding/decoding systems evaluation. There are two alternative ways of compressed video quality evaluation: perceptual (sometimes called subjective) and computational (also referred to as objective). No matter what the method is, the crucial role in results of a coder evaluation is played by the scene selection. The algorithm (or the whole system) performance is strictly dependant on the amount of perceptual information that the picture contains. In case of a video, the perceptual information can be divided into spatial and temporal. Test sequences must span the full range of spatial and temporal information of interest to users of the system under test. Considering test sequence
selection, the need to quantify the amount of this information seems to be obvious.

2. SI and TI according to ITU Recommendations

The spatial and temporal information measures proposed by International Telecommunication Union [1] are represented by single values for the whole test sequence.

The SI (Spatial perceptual Information) takes into consideration the luminance plane only and is computed on the base of Sobel filter. Each video frame at time \( n \) (\( F_n \)) is transformed with the Sobel filter [Sobel(F\(_n\))]. Then the standard deviation over the pixels (\( \text{std}_{\text{space}} \)) in each Sobel-filtered frame is computed. This operation is repeated for each frame in the video sequence and afterwards the maximum value in the time series (\( \text{max}_{\text{time}} \)) is chosen:

\[
SI = \max_{\text{time}} \left\{ \text{std}_{\text{space}} \left[ \text{Sobel} \left( F_n \right) \right] \right\}
\]  

(1)

The TI (Temporal perceptual Information) is also based on a luminance plane and calculates the motion. The motion is considered to be the difference between the pixel values at the same location in space but at successive frames: \( M_n(i, j) \). \( M_n(i, j) \) is therefore a function of time (\( n \)) and it is defined as:
\begin{align}
M_n(i, j) &= F_n(i, j) - F_{n-1}(i, j) \tag{2}
\end{align}

where \( F_n(i, j) \) is the pixel value at the \( i^{th} \) row and \( j^{th} \) column of \( n^{th} \) frame in time.

The measure of \( TI \) is calculated as the maximum over time (\( \max_{\text{time}} \)) of the standard deviation over space (\( \text{std}_{\text{space}} \)) of \( M_n(i, j) \) over all \( i \) and \( j \).

\begin{align}
TI &= \max_{\text{time}} \left\{ \text{std}_{\text{space}} [M_n(i, j)] \right\} \tag{3}
\end{align}

SI and TI are usually computed for the whole sequence, so each scene is described by two parameters. Higher values of SI and TI represent sequences which are more difficult to decode and are more likely to suffer from impairments. In order to choose scenes which will span as wide range of information to decode as possible, usually SI and TI are put in the TI(SI) plot and the scenes with the uttermost values are selected.

3. SI and TI new approach

Authors conducted Single Stimulus Continuous Quality Evaluation method [2, 3, 4], using 4 sequences (each 15 seconds long) coded with 13 GOP, all three possible GOP structures (with 1, 2 or without B frames) and with 5 levels of bitrate in a range of 2 Mbps to 5 Mbps. Hence, the test material was 30 minutes long and contained 15 variants of coding each of 4 test sequences. 45 subjects participated in the research. The voting signal was sampled at 2 Hz frequency.

Fig.2. The average score given in time to 4 sequences across the whole bitrate range
The interesting observation was that the lowest grade was always given to the sequence ‘mobl’ or ‘bbc3’, while ‘cact’ scene used to get scores close to the easiest to decode – ‘susie’ (fig. 2). According to SI and TI parameters, ‘cact’ was the sequence with the highest TI value and should contain clearly visible impairments (fig. 1a), which were supposed to affect the mean score given by observers.

This phenomenon impelled authors to investigate the variability of SI and TI in time. For this purpose both parameters were calculated on frame by frame basis. The intriguing discovery was that the high level of TI for ‘cact’ sequence was caused by one extraordinary peak, which falls on the frames with scene cut (fig. 3). Although it may cause some problems with coding, observers seem not to react to this incident at all (fig. 2).

![Fig.3. The TI (computed for each frame) distribution in time for 4 test sequences](image_url)

As the initial role of SI and TI parameters was to reflect perceptual amount of information, authors propose a slight modification in the way those parameters are computed, so that the values were in accordance with the level of scene complication perceived by the observer:

\[
Q_3.SI = \text{Upper quartile}_{time} \{\text{std}_{space} [\text{Sobel}(F_n)]\} 
\]

\[
Q_3.TI = \text{Upper quartile}_{time} \{\text{std}_{space} [M_n(i,j)]\}
\]