Institutionen för systemteknik, Reglerteknik

Linköping studies in science and technology.
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# **Errata / Addendum** for

# On Modeling and Diagnosis of Friction and Wear in Industrial Robots

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## Notation

Page **xviii**, line **5**:

. . . load torques which is to . . .

*should read*

. . . load torques which is aligned to . . .

## Chapter 1

Page **3**, line **-18**:

. . . of wear is that affects friction . . .

*should read*

. . . of wear is that it affects friction . . .

Page **3**, line **-13**:

. . . are typically at least as significant . . .

*should read*

. . . are typically as significant . . .

Page **4**, line **5**:

of published papers.

*should read*

of published and submitted papers.

Page **5**, line **-11**:

. . . caused by temperature and load to friction . . .

*should read*

caused by temperature to friction.

Page **5**, line **-2**:

. . . method developed was carried out as a . . .

*should read*

. . . method proposed was developed as a . . .

## Chapter 2

Page **18**, line **11**:

An accurate dynamic models is . . .

*should read*

An accurate dynamic model is . . .

## Chapter 3

Page **27**, line **15**:

. . . of the phenomena.

*should read*

. . . of the phenomenon.

Page **27**, line **-6**:

For constant velocities, . . .

*should read*

For $\dot{z} = 0$, . . .

## Chapter 4

Page **33**, line **-2**:

. . . laboratory analyzes.

*should read*

. . . laboratory analyses.

Page **35**, line **-16**:

The fault indicator is essentially . . .

*should read*

The fault indicator generation is essentially . . .

Page **36**, line **-4/-3**:

. . . and if some parameters are unknown, it is . . .

*should read*

. . . and if there are unknown parameters, it is . . .

Page **40**, line **-12**:

for a constant $v$

*should read*

for a positive constant $v$

Page **42**, line **-11**:

. . . on the system operational points . . .

*should read*

. . . on the system's operational points . . .

Page **48**, line **7**:

. . . is however symmetric and also a metric, satisfying the triangle inequality.

*should read*

. . . is however symmetric but is not a metric since it does not satisfies the triangle inequality.

Page **48**, line **10**:

. . . Hellinger distance . . .

*should read*

. . . Hellinger metric . . .

Page **49**, line **13**:

The distance is also a metric and therefore . . .

*should read*

The distance is symmetric and therefore . . .

Page **49**, line **15**:

. . . torque is affect by the . . .

*should read*

. . . torque is affected by the . . .

## Chapter 5

Page **53**, line **-3**:

. . . $\tau_m = Ki_m$ is possible.

*should read*

. . . $\tau_m = Ki_m$ are possible.

## Paper A

Page **73**, line **-14**:

For constant velocities, . . .

*should read*

For $\dot{z} = 0$, . . .

Page **76**, line **11**:

. . . the friction torques at joints.

*should read*

. . . the friction torques at the joints.

Page **77**, line **-3**:

. . . if there are no linear . . .

*should read*

. . . if there is no linear . . .

## Paper B

Page **99**, line **-12**:

. . . is discussed and

*should read*

. . . is found and

Page **101**, line **-5**:

. . . is a design criteria, representing. . .

*should read*

. . . is a design criterion, representing. . .

Page **104**, line **-9**:

. . . velocity slope dependecy at . . .

*should read*

. . . velocity slope dependency at . . .

Page **105**, line **6**:

$F_{s,\mathsf{w}} = 9.10\,10^{-3}$

*should read*

$F_{s,\mathsf{w}} = 9.10\,10^{-4}$

## Paper C

The Kullback-Leibler distance of Equation (5) does not satisfies the triangle inequality. Therefore, in general, Equation (6) does not hold.

This does not seem to affect the use of the left-hand side of (6) as a fault indicator, as presented in Section 3. Due to noise, the quantities $\mathrm{KL}\left(\hat{p}^{k-1}||\hat{p}^{k}\right)$ will typically be positive even under similar wear levels. The inequality (6) will therefore hold for some value of $j$.

An alternative to the use of the Kullback-Leibler distance is to use the Hellinger metric. For two continuous distributions on $y$, $p(y)$ and $q(y)$, it is defined as

$$\mathrm{H}\left(p,q\right) = \left[\frac{1}{2}\int_{-\infty}^{\infty}\left(\sqrt{p(y)}-\sqrt{q(y)}\right)^{2}\mathrm{d}y\right]^{1/2}. \tag{1}$$

Notice that $\mathrm{H}\left(p,q\right) = \|\sqrt{p(y)}-\sqrt{q(y)}\|_2$ and it therefore satisfies the triangle inequality. Thus, the inequality

$$\mathrm{H}\left(\hat{p}^{0},\hat{p}^{j}\right) \leq \sum_{k=1}^{j}\mathrm{H}\left(\hat{p}^{k-1},\hat{p}^{k}\right) \tag{2}$$

holds for the Hellinger metric. A reviewed version of Paper C is published as an updated version of technical report 3040 and publicly available in [1]. In the publication, the Hellinger metric is used instead of the Kullback-Leibler distance. The qualitative results and ideas are very similar to what is presented in Paper C.

## References

[1] A. C. Bittencourt, K. Saarinen, and S. Sander-Tavallaey. A data-driven method for monitoring systems that operate repetitively - applications to robust wear monitoring in an industrial robot joint. Technical Report LiTH-ISY-R-3040, Department of Electrical Engineering, Linköping University, http://www.control.isy.liu.se/research/reports/2011/3040.pdf, Dec. 2011. Reviewed on 16-Feb-2012.