CONTROL SYSTEM AND FAULT DETECTION ALGORITHM FOR A RESTORED TEETH FATIGUE ASSAY MACHINE

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SUMMARY

- Introduction
- Machine requirements
- Machine and control system description
- Machine operation
- Fault detection algorithm
- Experimental results
- Conclusions
INTRODUCTION

- Necessities for dental restorations in Dentistry field
  - Optimal design of the restored teeth
  - Posts of different material and geometry
  - Tested with time-varying forces
  - Knowing which component fails first
MACHINE REQUIREMENTS

- Test different posts (material and geometry) of restored teeth
- Emulate the mastication forces
  - Application of time-varying forces
- Number of mastication cycles before the failure of the tooth
  - Fault detection
- Knowing which component fails first
  - Automatic stop of forces application
FATIGUE ASSAY MACHINE
DESCRIPTION
MACHINE OPERATION

- Force calibration:
  - Torque reference ($u_k$) vs. Measured force ($F_k$)
MACHINE OPERATION

- Specimen fatigue assay
  - From required force ($F_k$) to Torque reference ($u_k$)
  - Measured position ($y_k$) depends on the fault ($f_k$)
Model-based fault detection

- Noisy model: \( y_k = g(\{u_k\}) + f_k + v_k \)
- Prediction model: \( \hat{y}_k = \hat{g}(\{u_k\}) \)
- Prediction error: \( e_k = y_k - \hat{y}_k \)
- Expected (fault free) prediction error: \( e_k = g(\{u_k\}) - \hat{g}(\{u_k\}) + v_k \)
  - This error can be bounded during the identification process
    \[ \| e_k \|_{RMS} \]
- Fault detection algorithm:
  - Failure occurs with probability of 99.74% if
  \[ |e_k| > 3\| e_k \|_{RMS} \]
Identification of the prediction model:

- LTV model

\[ \hat{y}_k = \hat{g}_k(\{u_k\}) = \hat{A}_k + \hat{B}_k \cdot u_{k-d} \]
FAULT DETECTION ALGORITHM

- Prediction error

![Graphs showing prediction error comparison for different frequencies](image-url)
FAULT DETECTION ALGORITHM

- FDA:
  - RLS
    \[ \psi_k = [1, u_{k-28}]^T \]
    \[ \gamma_k = \frac{P_k \psi_k}{\lambda + \psi_k^T P_k \psi_k} \]
    \[ \hat{\theta}_k = \hat{\theta}_k + \gamma_k (y_k - \psi_k^T \hat{\theta}_k) \]
    \[ \hat{\theta}_k = [\hat{A}_k, \hat{B}_k]^T \]
    \[ P_k = \frac{1}{\lambda} (I - \gamma_k \psi_k^T) P_{k-1} \]
    \[ \hat{y}_k = \psi_k^T \hat{\theta}_k \]
    \[ e_k = y_k - \hat{y}_k \]

- Adaptive threshold
  \[ \hat{\sigma}_k^2 = \beta \hat{\sigma}_{k-1}^2 + (1 - \beta) e_k^2 \]
  \[ \hat{\sigma}_k \approx \|e_k\|_{RMS}^2 \]

\[ \begin{cases} 
  \text{If } |e_k| < p \cdot \hat{\sigma}_k & \text{No fault} \\
  \text{If } |e_k| \geq p \cdot \hat{\sigma}_k & \text{Fault}
\end{cases} \]
FAULT DETECTION ALGORITHM

- **Tuning process**
  - **Forgetting factor** $\lambda$
    - As big as possible to detect slow changes on the process
    - Big enough to avoid changes on the parameters due to faults
  - **Filter pole used to approximate** $\|e_k\|_{RMS}$ $\beta$ :
    - Big enough to approximate properly
    - Small enough to initiate the application
  - **False alarm ratio related parameter** $\rho$:
    - Small enough to detect the faults as fast as possible
    - Big enough to avoid false alarms
EXPERIMENTAL RESULTS

- Prediction error and threshold

\begin{align*}
\text{time(s)} & = 0, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000 \\
\text{Prediction error and threshold} & \text{vs. time(s)} \\
\end{align*}
EXPERIMENTAL RESULTS

- Tooth failure
CONCLUSIONS

- Development of a fatigue assay machine for studying the dynamical behaviour of restored teeth
- The control system has been described
- The machine operation has been described
- The fault detection algorithm has been addressed
- The tuning process has been carried out
- Experimental results have been discussed
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