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Sliding mode controller for a feedback accelerometer with a distributed mass

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Abstract: The design, modelling and analysis of a prototype feedback based accelerometer is presented. A distributed Mass Spring Damper model is used to formulate the model for guitar string with a proof mass via Euler Bernoulli beam theory. A sliding mode controller is formulated through performance parameters which include the settling time and overshoots in the proof mass. Comparative results of Euler Bernoulli based sliding mode analysis versus the proportional controllers are used to demonstrate the superiority of the sliding mode approach. The key contribution is formulating a criterion for sliding mode control of a Euler-Bernoulli distributed mass problem.

Keywords: accelerometer, Controller, Euler Bernoulli, Electromagnets, Proof mass

An accelerometer is an instrument used to measure acceleration or to detect and determine vibration (Varum, 2013). It measures acceleration through conversion of motion into an electrical signal (Watson, 2006). It is commonly used in various applications for instance control systems and navigation guidance (Majlis et al., 2002). It may be used in the measurement of vibration, motion, shock and seismic. A standard accelerometer comprises of a proof mass, spring and damper with a casing (Krishnan et al., 2007). When the casing encounters motion, it is propelled with an acceleration causing the proof mass within the casing to move. Given steady state conditions, the force acting on the mass is balanced by the tension in the spring. The extension of the spring provides a measure of the applied force which is proportional to the acceleration (Krishnan et al., 2007). A basic accelerometer is usually modified resulting in a Micro Mechanical System (MEMs) or pendulous accelerometer. The merits of a pendulum accelerometer include its high resolution, dynamic range, capacity to handle strategic thrust axis and its linearity (Vohra et al., 1997). Optical and feedback accelerometers in comparison to piezo-resistive, electrodynamics and open loop accelerometers have a wide frequency range, are more accurate and are mostly non-contact.

(Macheiner and Brunner, 2009) designed a fibre optic cantilever sensor that is used for static and kinematic tilt determination. The sensor has a very high precision and range. (Villnow et al., 2011) develop and investigates a novel fibre optical accelerometer with a capacity to operate in extreme conditions. This sensor can be used to monitor vibrations and can withstand very high temperatures. (Lopez-Higuera et al., 1996) designed a fibre optic accelerometer that measures accelerations ranging from small to medium sized frequency with ability to withstand very high temperatures. It can therefore be concluded that fibre optics accelerometers have very high precision, range and can operate under extreme conditions.

The guitar string can be characterized as a cantilever beam hence it can be modelled using several methods. Some of these methods include the spring- mass damper model and the Euler Bernoulli beam theorem. The Mass Spring Damper (MSD) (Bentley, 2005) is easy to formulate and implement, however, this model lumps some parameters therefore it does not provide an accurate representation of the system behaviour. To mitigate this problem, The Euler Bernoulli beam theory is used together with its boundary conditions. The Euler-Bernoulli beam model has a demerit of over estimating the spatial frequencies (Bashash et al., 2008). Euler-Bernoulli's final equation with no closed form solution can be solved using analytical techniques for instance Assumed Modes Method (ASM) (Bashash et al., 2008). Ordinary Differential equations (ODEs)are used to describe the lumped parameter model whereas the distributed beam models are described using Partial Differential Equations (PDEs)(Bashash et al., 2008). The lumped parameter model have a demerit of having high mass and as a result an increase in energy usage and high inertial forces. (Bashash et al., 2008) documents four models of transversely vibrating uniform beam models.

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These models are: the Euler Bernoulli, Rayleigh, Shear and Timonshenko. Boundary and initial conditions of the PDEs are used to describe this models. The slenderness ratio (The ratio of the fibre diameter to the beam length) of the pendulum for the system described in section 1 was found to be greater than 100 thus the Euler Bernoulli beam theorem was applicable.

Controllers are designed to minimize uncertainties in a control system. The proportional controller which is linear provides an immediate action to the controller. It is simple and easy to implement. However, it only has one tuning parameter which makes it difficult to use in systems that have multiple parameters. The proportional controller also is unable to handle abrupt large deviations between the input and output in the system. The root locus can be used with the proportional controller to find a comprise to the system's critical parameters for instance damping and stability. However, given a system that needs constant monitoring of stability, steady state error and damping, the proportional controller with root locus is not sufficient (Zhu et al., 2013). Proportional Intergral Deriative (PID) is a control technique employed to deal with issues experienced by using the proportional controller. It is based on three controllers namely The proportion which provides instant response to the control error, Integral which drives the constant error to zero and the derivative which acts upon the change of the error. It has the advantages of having three gain parameters that can be tuned to achieve better results. However, it is a linear controller and can not handle uncertainties within the system brought about by the complexity of the system (Ang et al., 2005). The sliding mode(SM) control technique is a non linear method known for its accuracy, robustness, easy tuning and implementation. It has the advantages of low sensitivity to a system's parameter variations and disturbances. It also reduces the complexity of feed back design by decoupling of the entire system into independent partial components of lesser dimensions. The ability to choose sliding mode functions ensures that the dynamic behaviour of a plant are tailored. The demerits of the sliding mode is that it has chattering (Utkin, 2008).

Electromagnets are used in numerous applications for instance in electronics and surgical operating theatre. They are also employed in control systems as position actuators. They have previously been used in high gain and precision magnetic levitation systems and pendulum control (Duka, 2010). Giron-Sierra (2001) documents the control of an inverted pendulum using an on and off action through two electromagnetic pendulum. The force relationship is found to be of an exponential form and depends on several constants, the distance between the electromagnets and the pendulum. Ida (2012) uses a mass with an embedded magnet in the model. The force generated in this model is determined by use of the Finite element method and the results are stored in a look up table. Austin and Wagner (2013) uses a spherical magnet for actuation in a system made up of a damper and a spring. Each element of the electromagnet is modelled as reluctance. The pendulum swings through an angle the model accounts for variation by determining the hypotenuse length. Due to their high gain and precision, electromagnets are commonly used for actuation.

The goal of this paper is to formulate a sliding mode controller through performance parameters which include the settling time and overshoots in the proof mass. The main contribution is formulating a criterion for sliding mode control of a Euler-Bernoulli distributed mass problem. The paper is structured as follows: Section 1 of the report has an introduction which includes problem formulation, research background and literature review. Section 2 details the system description. It is followed by the modelling of the system and controllers in section 3. The results and discussion are presented in section 4 and 5. Recommendations and future work are in section 6 and 7 respectively.

1. SYSTEM DESCRIPTION

Figure 1 and 2 below show pictorial view of the built prototype and the physical diagram.

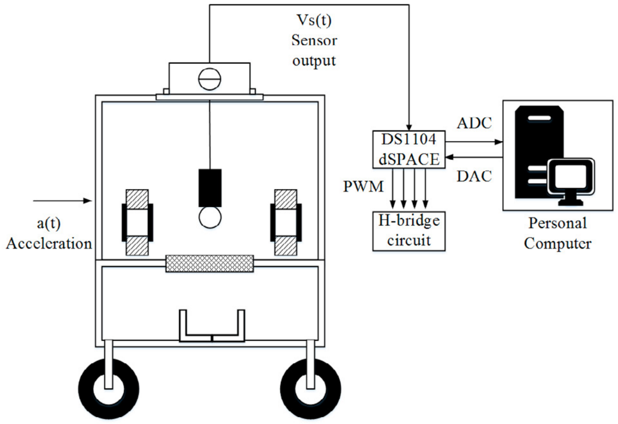

Fig. 1. Schematic view of the accelerometer.

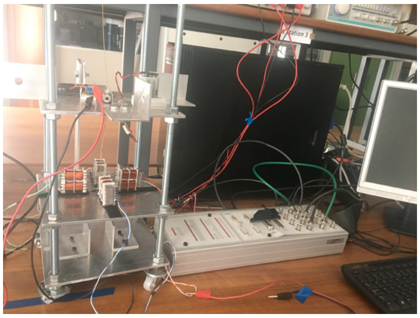

Fig. 2. pictorial view of the accelerometer.

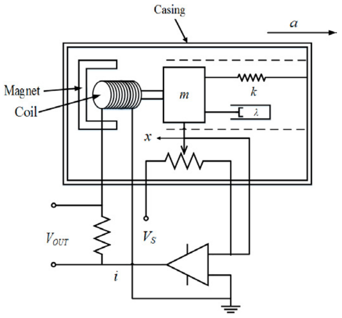

Fig. 3. Physical diagram of the accelerometer.