applied sciences

Editorial

Advances in Mechanical Systems Dynamics 2020

Alberto Doria [1,*], Giovanni Boschetti [2] and Matteo Massaro [1]

[1] Department of Industrial Engineering, University of Padova, 35131 Padova, Italy; matteo.massaro@unipd.it
[2] Department of Management and Engineering, University of Padova, 36100 Vicenza, Italy; giovanni.boschetti@unipd.it
* Correspondence: alberto.doria@unipd.it; Tel.: +39-049-827-6803

1. Introduction

The fundamentals of mechanical system dynamics were established before the beginning of the industrial era. The 18th century was very important for science and was characterized by the development of classical mechanics. This development went on in the 19th century and new important applications related to industrialization were found and studied. The development of computers in the 20th century revolutionized mechanical system dynamics owing to the development of numerical simulation. Nowadays we are in the presence of the fourth industrial revolution. Mechanical systems are increasingly integrated with electrical, fluidic, and electronic systems and the industrial environment is going to be characterized by the cyber-physical systems of Industry 4.0. In this framework, the state-of-the–art will be represented soon by integrated mechanical systems, supported by accurate dynamic models able to predict their dynamic behavior. Therefore, mechanical systems dynamics will play a central role in the coming years. This Special Issue aims at disseminating the latest research findings, and ideas in the field of mechanical systems dynamics, with particular emphasis on novel trends and applications.

Citation: Doria, A.; Boschetti, G.; Massaro, M. Advances in Mechanical Systems Dynamics 2020. *Appl. Sci.* **2021**, *11*, 2352. https://doi.org/10.3390/app11052352

Received: 3 March 2021
Accepted: 4 March 2021
Published: 6 March 2021

2. Present Trends in Mechanical Systems Dynamics

The 20 papers collected in this Special Issue refer to different areas of engineering (automotive, manufacturing, and civil engineering) and to very different applications. Nevertheless, they clearly highlight the presence of some important trends in the methods, developments, and challenges of the present research on mechanical systems dynamics.

2.1. Multi-Physics Modeling and Simulation

Until a few years ago, multi-physics modeling and simulation were restricted to some specific fields of research, such as electromechanical problems, vibroacoustic problems, and flow-induced vibrations. The development of powerful codes for multi-physics simulation and the need for detailed analyses of the performance of new devices that require a multi-physics approach (e.g., vibration energy harvesters) have strongly increased the interest in multi-physics analysis. Many papers collected in this Special Issue deal with new developments and/or applications of modeling and simulation.

Papers [1,2] deal with multi-physics modeling and simulation of tires. In [1], the well-known Tire Magic Formula is coupled with a thermal model. In [2], the Fourier equations for thermal analysis are coupled with a tire structural model.

Paper [3] deals with a new and specific application: a liquid handling robot. Computational fluid dynamics was employed to capture the motion of the fluid inside a tank carried by a walking robot.

In [4], the noise vibration and harshness (NVH) of a full engine is carried out coupling a multi-body model of the moving components, with FE models of the structural elements and an acoustic model based on the wave-based technique (WBT). The advantages of coupled simulations are highlighted.

Finally, in [5] a novel vibration energy absorbing mechanism for cables is presented. Since it includes non-linear magnetic springs and hydraulic dampers, a coupled model is developed. The advantages of this multi-physics damper are shown.

2.2. Non-Linear Analysis

Non-linear phenomena are inherent in many natural and engineering systems. Very typical examples of non-linear behavior can be found in tire mechanics and in robot dynamics. Until recently, the presence of non-linearities hindered the analysis and the design of mechanical systems, but nowadays the development of numerical methods allows the exploitation of non-linear phenomena in many fields of industry. In this Special Issue, there are many papers that address non-linear problems.

Papers [4,6] deal with non-linear contact problems in piston-liner interaction and in rolling bearings, respectively.

Paper [7] addresses the problem of vibratory conveying of cylindrical parts, a non-linear numerical model is developed that takes into account the transition between pure rolling and rolling with sliding and the impacts of the cylindrical parts with the edge of the conveyor.

In [5], non-linear stiffness properties are exploited to dampen cable vibrations. Finally, in [8], non-linear effects are estimated to find chain transmission efficiency.

2.3. Identification of Dynamic Systems

The development of the dynamic models of cyber-physical systems requires detailed knowledge of the parameters of the systems. Therefore, identification techniques are very important and have to cope with many problems, such as the presence of non-linearities, noisy data, and new material properties. In most cases, the identification of a mechanical system is based on modal testing, but new technologies based on moving sensors and swarms of sensors are under development. In this Special Issue, four papers focus on identification problems.

Paper [9] deals with the identification of the visco-elastic properties of materials used to dampen vibrations in industrial and civil engineering.

In [10], experimental modal analysis is used to identify the stiffness and damping properties of the joints of industrial robots, which can influence the performance of automatic robotic assembly and material removal processes.

The friction parameters (Stribeck friction model) of a parallel kinematics mechanism with prismatic joints are identified in [11].

Finally, in [4], the numerical modes of vibration of an engine are validated and updated, with an experimental modal analysis.

2.4. Control Strategies and Motion Planning

Presently, more and more mechanical systems are being controlled, with the aim of adjusting their dynamics. Trajectory and motion planning are increasingly relevant in robots and in other mechanical systems. Indeed, the goal of achieving ever-higher speeds is extending into all fields of mechanics. In order to preserve accuracy and repeatability, proper strategies should be adopted in order to generate trajectories that could be executed at high speed, while avoiding excessive motor accelerations and mechanical structure vibrations.

In [12], an active rear axle independent steering system of a ground vehicle is developed adopting a hierarchical synchronization control strategy. In [13], a driver-aid system to improve directional stability of articulated vehicles is developed. Finally, in [14], the driver–steering wheel interaction in emergency situations is dealt with in the framework of the development of advanced driver assistance systems.

2.5. Man–Machine Interaction

Man–machine interaction is becoming increasingly important in the automotive sector. Indeed, the design of advanced driver assistance systems (ADAS) in four-wheeled vehicles is resulting in complex interactions between the driver and vehicle while in two-wheeled vehicles the importance of the rider–vehicle interaction on the vehicle stability has been recognized. In this Special Issue, the investigation of the driver–steering interaction is experimentally carried out in [14], with an instrumented steering wheel, while in [15] the effect of the rider's passive vibration on the stability of a two-wheeled vehicle is considered, with a focus on the weave and wobble modes. Finally, in [16], the most used biomechanical models are compared and employed to build a multibody rider model suitable for multibody applications.

3. Fields of Application

3.1. Machine Elements

Mechanisms, gears, and transmissions are still key elements of advanced industrial systems, automatic machines, and robots. To improve the performance of the system, detailed models of machine elements, taking into account non-linearities or time-variant properties, are needed. This Special Issue includes three papers that cover the modeling and simulation of machine elements.

The first of these deals with the dynamics of cylindrical parts in a vibratory conveyor [7]. A non-linear numerical model is developed, taking into account pure rolling, rolling with sliding, and the impacts on the edges. A comparison between numerical and experimental results guarantees the effectiveness of the method.

A method for the dynamic parameter identification in parallel mechanisms is proposed in [11]. Non-negligible friction has been incorporated in the dynamic model, and a bound-constrained optimization technique was employed to minimize the residual errors while maintaining the physical feasibility of the solutions.

A novel approach for estimating the efficiency of roller chain power transmission systems is proposed in [8]. It is based on sliding friction losses and damping force. The effects of rotational speed, load, derailleur system, and damping coefficient on transmission efficiency were analyzed. The test was set up to verify the estimated efficiency, and the results highlight a good correlation, demonstrating the validity of the estimation.

3.2. Noise and Vibration Control

Vibrations and noise are a potential problem for any application that includes moving components. For many years, the increase in working speed has been a typical trend of machines, but often the increased speed leads to high levels of vibrations and noise, which have to be controlled. The Internet of things and the fourth industrial revolution are characterized by networks of sensors that monitor industrial plants, machines, and vehicles. On the one hand, the sensors' performance and durability can be affected by high amplitude vibrations; on the other hand, environment vibrations can be exploited to feed the distributed sensors adopting vibration energy harvesting technologies based on piezoelectric, electromagnetic, and capacitive phenomena. In the Special Issue, there are four papers that focus on noise and vibration control. Paper [6] deals with machinery vibrations and presents a simplified approach for the analysis of varying compliance vibrations of rolling bearings. New viscoelastic materials are frequently adopted to control and dampen vibrations, in [9], two generalized formulations of viscoelastic materials are deeply analyzed and a comparison with experimental results is made. In [4], the problem of noise vibrations and harshness (NVH) in engines is considered. A coupled model, including an FE model of the structural parts and a multi-body model of valve train dynamics, is developed. An interesting comparison between results obtained with un-coupled and coupled models is made. Finally, in [5], a novel vibration absorbing mechanism for cables is presented. It exploits multi-physical components (magnetic springs and hydraulic cylinders). The mechanical design and the mathematical model of the mechanism are developed, and numerical results are presented; future applications will include stayed bridges.

3.3. Robotics

Robotics is a science in continuous evolution and the efforts of the researchers consist of improving more and more its ability to help operators in their work and to solve their problems. Many works have addressed the performance evaluation and the safety improvement of industrial manipulators. This Special Issue includes three papers dealing with robotics. One of these deals with the issue of liquid handling [3]. In these applications, the problem of sloshing has to be considered as a parameter that can affect the stability of the system. In the paper, a proper motion planning algorithm is proposed to solve the liquid transport problem.

In [10], a compliant joint dynamic model of an industrial robot, based on a modal approach, has been proposed. A novel testing method has been developed, in order to excite the mode of vibration of one-by-one joints, in order to identify each joint stiffness. By means of the developed dynamic model, it is possible to predict the variation of the natural frequencies in the workspace.

Finally, in [17], a recovery strategy for cable robots in case of cable failure is presented and discussed. The paper, making use of a proper performance index, improves on previous works by considering the actuator dynamics. Simulation results prove the feasibility and the effectiveness of the presented approach.

3.4. Cars and Heavy Vehicles

This Special Issue includes six papers dealing with cars and heavy vehicles.

The modeling and simulations of tires are still classic, especially when it comes to the modeling of the effect of temperature on the tire performance. In [1], an extension of the well-known Magic Formula is derived in order to include the effect of temperature on car tires: new coefficients are added to account for changes in longitudinal and cornering stiffness as well as peak factors. In addition, the thermal model is extended.

The handling of trucks is considered in [18], with a focus on the effects of taper-leaf vs. multi-leaf suspensions on handling. The drift test, the ramp steer test, the step steer, and brake-in-turn tests are simulated in a multi-body environment, after validation of the numerical model in steady-turning conditions.

Independent active rear steering is the most flexible approach to rear steering of road vehicles. A two-level hierarchical synchronization control strategy is proposed in [12]. The upper controller adopts a virtual synchronization controller based on a dynamic model of the virtual rear axle steering mechanism to reduce the synchronization error between the rear wheel steering angles, while the lower controller is designed to realize an accurate tracking control of the steering angle for each wheel and reject disturbances. Experimental results on the prototype vehicle are shown.

Heavy-wheeled vehicles with articulated hydraulic steering systems are widely used (e.g., in construction and road building). However, they often suffer from poor directional stability. A driver-aid system aimed at improving the directional stability is presented in [13], based on the steering wheel rotation, a frame articulation sensor, and an additional hydraulic circuit for straightening the frame.

Farming tracked vehicles on deformable soils are considered in [19]. A multibody approach is employed. The two flexible tracks are modeled as groups of rigid links constrained by bushing elements able to replicate the elastic behavior of the track. A soil model is used to describe the terrain behavior subjected to the grouser's action.

The interaction of the driver with the vehicle's steering has been investigated in the past both in the case of cars and motorcycles. In [14], the focus on an instrumented steering wheel (ISW) is employed to investigate the driver's response to a lateral disturbance (the so-called "kick-plate" maneuver) on the vehicle dynamics. A notable feature of the work is that the ISW employed is capable of measuring the force and moment applied by each hand separately. An involuntary torque peak is observed after the disturbance before the voluntary (recovery) torque is applied, both in one- and two-hands maneuvers.

3.5. Light Vehicles

In the near future, light vehicles equipped with an electric or hybrid propulsion system will give a large contribution to sustainable mobility in urban areas. This Special Issue includes four papers dealing with light vehicles.

The thermodynamic modeling of motorcycle tires is considered in [2], where a physical model accounting for sources of heating such as friction power at the road interface and the cyclic generation of heat because of rolling and to asphalt indentation, and for the cooling effects because of the air forced convection, to road conduction and to turbulences in the inflation chamber is proposed. A special focus is the modeling of the contact patch and the need for real-time capabilities.

The characterization of mountain bike tires is addressed in [20], which is a topic rarely covered in the literature, which is mainly focused on cars and motorcycle tires. The work presents laboratory measurements of inflated tire profiles, tire contact patch footprints, force and moment data, as well as static lateral and radial stiffness.

It is well known that the inertial properties of riders affect the stability of two-wheeled vehicles and that there are different reference biomechanical databases for the estimation of such parameters. A review and a comparison focused on multibody applications is presented in [16].

Finally, an analysis of the weave and wobble vibrations of motorcycles is reported in [15], with a focus on the effect of a flexible fork on wobble stability and the effect of the change in the shape of the weave mode on its stability.

4. Conclusions

This Special Issue contains twenty interesting research papers focused on advances in mechanical systems dynamics, covering a wide area of applications. In most of the papers of the Special Issue, numerical results are corroborated by experimental results.

This collection shows the actuality of this topic and gives hints about future developments and applications.

Author Contributions: Conceptualization, A.D., G.B., and M.M.; writing—original draft preparation, A.D., G.B., and M.M.; writing—review and editing, A.D., G.B., and M.M.; supervision, A.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable

Informed Consent Statement: Not applicable

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Harsh, D.; Shyrokau, B. Tire Model with Temperature Effects for Formula SAE Vehicle. *Appl. Sci.* **2019**, *9*, 5328. [CrossRef]
2. Farroni, F.; Mancinelli, N.; Timpone, F. A Real-Time Thermal Model for the Analysis of Tire/Road Interaction in Motorcycle Applications. *Appl. Sci.* **2020**, *10*, 1604. [CrossRef]
3. Usman, M.; Sajid, M.; Uddin, E.; Ayaz, Y. Investigation of Zero Moment Point in a Partially Filled Liquid Vessel Subjected to Roll Motion. *Appl. Sci.* **2020**, *10*, 3992. [CrossRef]
4. Zheng, X.; Luo, X.; Qiu, Y.; Hao, Z. Modeling and NVH Analysis of a Full Engine Dynamic Model with Valve Train System. *Appl. Sci.* **2020**, *10*, 5145. [CrossRef]
5. Qin, Z.; Wu, Y.; Huang, A.; Lyu, S.; Sutherland, J. Theoretical Design of a Novel Vibration Energy Absorbing Mechanism for Cables. *Appl. Sci.* **2020**, *10*, 5309. [CrossRef]
6. Tomovic, R. A Simplified Mathematical Model for the Analysis of Varying Compliance Vibrations of a Rolling Bearing. *Appl. Sci.* **2020**, *10*, 670. [CrossRef]
7. Comand, N.; Doria, A. Dynamics of Cylindrical Parts for Vibratory Conveying. *Appl. Sci.* **2020**, *10*, 1926. [CrossRef]
8. Zhang, S.; Tak, T. Efficiency Estimation of Roller Chain Power Transmission System. *Appl. Sci.* **2020**, *10*, 7729. [CrossRef]

9. Genovese, A.; Carputo, F.; Maiorano, A.; Timpone, F.; Farroni, F.; Sakhnevych, A. Study on the Generalized Formulations with the Aim to Reproduce the Viscoelastic Dynamic Behavior of Polymers. *Appl. Sci.* **2020**, *10*, 2321. [CrossRef]
10. Bottin, M.; Cocuzza, S.; Comand, N.; Doria, A. Modeling and Identification of an Industrial Robot with a Selective Modal Approach. *Appl. Sci.* **2020**, *10*, 4619. [CrossRef]
11. Rosyid, A.; El-Khasawneh, B. Identification of the Dynamic Parameters of a Parallel Kinematics Mechanism with Prismatic Joints by Considering Varying Friction. *Appl. Sci.* **2020**, *10*, 4820. [CrossRef]
12. Deng, B.; Zhao, H.; Shao, K.; Li, W.; Yin, A. Hierarchical Synchronization Control Strategy of Active Rear Axle Independent Steering System. *Appl. Sci.* **2020**, *10*, 3537. [CrossRef]
13. Lopatka, M.; Rubiec, A. Concept and Preliminary Simulations of a Driver-Aid System for Transport Tasks of Articulated Vehicles with a Hydrostatic Steering System. *Appl. Sci.* **2020**, *10*, 5747. [CrossRef]
14. Comolli, F.; Gobbi, M.; Mastinu, G. Study on the Driver/Steering Wheel Interaction in Emergency Situations. *Appl. Sci.* **2020**, *10*, 7055. [CrossRef]
15. Passigato, F.; Eisele, A.; Wisselmann, D.; Gordner, A.; Diermeyer, F. Analysis of the Phenomena Causing Weave and Wobble in Two-Wheelers. *Appl. Sci.* **2020**, *10*, 6826. [CrossRef]
16. Bova, M.; Massaro, M.; Petrone, N. A Three-Dimensional Parametric Biomechanical Rider Model for Multibody Applications. *Appl. Sci.* **2020**, *10*, 4509. [CrossRef]
17. Boschetti, G.; Minto, R.; Trevisani, A. Improving a Cable Robot Recovery Strategy by Actuator Dynamics. *Appl. Sci.* **2020**, *10*, 7362. [CrossRef]
18. Zhao, L.; Zhang, Y.; Yu, Y.; Zhou, C.; Li, X.; Li, H. Truck Handling Stability Simulation and Comparison of Taper-Leaf and Multi-Leaf Spring Suspensions with the Same Vertical Stiffness. *Appl. Sci.* **2020**, *10*, 1293. [CrossRef]
19. Mocera, F.; Somà, A.; Nicolini, A. Grousers Effect in Tracked Vehicle Multibody Dynamics with Deformable Terrain Contact Model. *Appl. Sci.* **2020**, *10*, 6581. [CrossRef]
20. Dressel, A.; Sadauckas, J. Characterization and Modelling of Various Sized Mountain Bike Tires and the Effects of Tire Tread Knobs and Inflation Pressure. *Appl. Sci.* **2020**, *10*, 3156. [CrossRef]