RESEARCH STATEMENT

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My research is underlying the area of robot control, mechatronics systems control and systems dynamics. My research program reflects and highlights the applicability of these subjects to diverse fields. The research approach emphasizes exploiting mathematical declaration and experimental verification of the proposed concepts. My main research, in the past few years till now, can be categorized into the following groupings with some overlap:

1) Human-Robot interactive systems
2) Control of robots and mechatronics systems
3) Innovation of fluid power systems

Past Research.

1. Stabilization of a loaded double inverted pendulum system

This research aimed to the design of a neuro-fuzzy based control system for the stabilization of a double inverted pendulum system in the upward position with a payload of significant mass attached to the second link. This was the M.Sc. dissertation topic. The addition of mass increases the complexity of the control problem and is important due to its relevance to real applications such as humanoid robots and mobile manipulators. The dynamic model of the system has been deduced, and an LQR-based (Linear Quadratic Regulator) controller has been proposed for stabilizing the system. An ANFIS-based (Adaptive Neuro-Fuzzy Inference System) controller has been designed to perform the task, based on training data from the optimal LQR controller. The performance of the ANFIS-based controller has been enhanced by using Genetic Algorithms (GA) to optimize the controller PID-like gains. The work has been implemented using MATLAB/Simulink. Two **IEEE**-*conference* papers have been published as a result of this work.

2. Non-prehensile manipulation planning of a multi-link object

This research aimed to the equilibrium area numerical analysis, with experimental verification, for non-prehensile manipulation of a three-rigid link object by two cooperative arms. This was the Ph.D. dissertation topic, belongs to the category of human-robot interaction. This work has been inspired by an assistive nursing robot project for manipulating a patient, where the system has been figured in the same way of a caregiver lifting a patient. It is the initial step for the most sophisticated process of human manipulation. In this work, the equilibrium contact area has been analyzed, associated with different interaction forces, for statically holding the object at all its possible configurations. The dynamic model of the system has been produced from which the static analysis has been discussed in the presence of the frictional effect and motion constraint. As a result, an equilibrium contact length is extending over a range of equilibrium contact angles leading to an equilibrium contact area for every object's configuration. Numerical equilibrium area results have been experimentally validated after that. Four original papers have been published from this work, one is rated as **Q1-ISI** *Journal* and another one is rated as **Q1-Scopus** *Journal* in addition to two **IEEE**-*conference* papers.

3. Design modification and control of quadrotor flying robots

This work aimed to overcome the limitation of conventional quadrotors due to the usage of only four rotational propellers. A coupled motion between non-zero inclination hovering and translational motion of the quadrotor arises from this conventional configuration. In this research, a novel design modification, with experimental verification, has been proposed to increase the quadrotor degrees of freedom. Four additional rotations for the four propellers grant over-actuated system that enhances the quadrotor maneuverability and unlimited hovering. Each propeller has been allowed to rotate about the axis perpendicular to the arm connecting it with the quadrotor body. The dynamic model of the modified quadrotor has been deduced. After that, a PID controller has been designed for controlling different motions of the modified quadrotor according to certain trajectories. The proposed design modification has been evaluated by hovering the quadrotor with different inclination angles as a first case, and a horizontal motion with zero inclination angle as a second one. An experimental system has been set-up for the quadrotor with the proposed modification from which the quadrotor motion of the second case has been experimentally verified. As a result of this work, two original papers have been published, one of them is **Q2-Scopus** *Journal* and the other one is **IEEE**-*conference* related to unmanned aircraft systems.

4. Development of a remotely controlled forklift truck

This research was incorporated to the undergraduate level and aimed to develop a remotely controlled hydraulic forklift truck that using re-chargeable batteries as a power source and can sustain lifting 500kg load. The design of the forklift is meant to be compact in size for the applications of both: utilization in material handling in workshops, and to be portable with large good trucks for handling goods on the truck. The proposed design of the truck consists mainly of two parts: the base and the mast. The base consists of two parts connected to each other by a universal joint that controls the truck direction through a steering mechanism. The base is provided by four wheels, where the two rear wheels are the driving ones. The mast, the part interacts with the load, is fixed to the front part of the base. The mast is capable of moving along both the longitudinal and vertical directions in addition to the rotation around the traverse one as a result of a tilting mechanism. All the five actuation mechanisms are hydraulically actuated, supplied by one pump derived by an electric motor. A microcontroller unit is utilized to control the hydraulic system and coordinate the motion the truck.

This research was granted by the *Academy of Scientific Research and Technology, Egypt* over the academic years 2016-2017 and 2017-2018.

5. Development of an automatic waste-segregation unit

This research was incorporated to the undergraduate level and aimed to develop a sensor-based automatic waste segregation unit. It could be considered as a mechatronic system, controlled using pneumatic-based actuation system and PLC as a control unit. The process begins with the waste collection and dumping it into a hopper provided by a simple mechanism to separate waste materials individually, transmitted after that over a conveyor belt. Upon sensing of individual sensors attached at different locations along the belt, respective pneumatic cylinders are energized, and the waste material is pushed into the respective box. Finally, the waste is pressed using pneumatic cylinders to introduce it in a compact form.

Current Research.

1. Development of a wearable robot for wrist-joint rehabilitation

Rehabilitation therapy is a crucial need due to increasing number of stroke and cerebral palsy patients. Affected wrist joints often show an increased spasticity and stiffness, caused by impairments of surrounding muscles and tendons. This research aims to design, control and experimental implementation of a light weight two Degrees of Freedom (2-DOFs) wearable robot for wrist-joint rehabilitation. This device is to provide the two capabilities of the wrist movement: extension-flexion and ulnar-radial motions which is not so much tolerated earlier. Pneumatic Artificial Muscles actuators (PAMs) are suggested to undertake the wrist 2-DOFs motion instead of the most common rigid ones due to their compliance and flexibility. Currently, the research is going on the design of the wearable robot followed by the dynamic analysis and a controller design to achieve the coordinated motion of the wrist joint. The robot is to be manufactured after that, incorporated with PAMs and correspondence pneumatic circuit, for performance validation.

2. Identification and control of indexing-cam mechanisms

Due to the advantages of high loading capacity, low noise, low vibration, and high reliability, indexing cam mechanisms are widely used in automated machinery. Recently, they are suggested to be incorporated with actuators in robotics applications. This research aims to design a control system for a scaled indexing-cam mechanism for the purpose of use in human-robot interaction systems. Currently, the research is going on the identification of the indexing-cam system parameters, that is crucial for accurate control, followed by the design of a control system.

Future Research.

My future research plans revolve around the following research directions:

The first track. **Surgical Robots**

- This work aims to the design, analysis and manufacturing of a flexible endoscopic arm, with micro-fluidic actuators, for Minimal Invasive Surgery (MIS). The suggestion of using fluidic-based actuation comes to overcome draws of conventional ones in addition to its compatibility with the biological tissue. Current platforms mainly rely on conventional cable-driven actuation, which is prone to friction and backlash which affect accuracy, controllability, and thus intuitiveness of the system. Also, other small-scale actuators like piezoelectric bimorph and shape memory alloy, require high voltage or current to operate and not guarantee a safe interaction with biological tissue. In addition to the usage of micro-fluidic actuators, the work proposes the possibility of monolithic integration of soft materials and micro-fluidic actuators without the need for manual intervention to assemble discrete parts. Silicon-based microelectromechanical systems (MEMS) microfabrication techniques are to be used to develop the device. Embedded sensors are to be integrated with the arm in the future.

The second track. **Intelligent Mechatronics Systems**

- This work aims to the design and manufacturing of a hybrid quadrotor-type wall-climbing robot. The development of such robot is promising for a class of applications like the inspection of high civil structures. The considered features are including the design of a robot pose change, wall sticking and wall locomotion mechanisms compatible the quadrotor design. The control algorithm of the robot with the previously mentioned features is to be designed. Throughout the robot fly and upon the surface detection, the control algorithm is implementing actuation of the orientation change mechanism of the robot to set the propellers axis perpendicular to the surface and after that actuating both the wall sticking and wall locomotion mechanisms respectively.

The third track. **Assistive Robotic Systems**

- To continue the research related to the wrist-joint rehabilitation wearable robot as a diverse of challenges is still arising. Re-design of the robot for the purpose of including the rotational DOF of the wrist joint as well as the extension-flexion and ulnar-radial motions is to be done. In addition, more sensors integration to the robot is to be considered like force/torque and electromyography (EMG) sensors for better performance of its motion. Meanwhile, an intelligent-based control system is to be proposed for the multi-sensors robot, and to overcome the difficulty of the control of PAMs due to their nonlinear characteristics.

The fourth track. **Robot Control**

- Friction description in robot-joints of industrial robots is crucial for the purpose of joint-control, especially in human-robot interaction environments, as well as joint condition monitoring. This work aims to produce precise friction model in robot joints followed by control system design with friction compensation in real-time. In industrial robots, excessive motion with varying load and joint angles lead to change of the frictional characteristics in robot joints and hence their motion. Most literature work relevant to the robot controllers with friction compensation depend on static friction models to describe the friction. However, these models are only related to the rotational velocity. Consideration of other factors like temperature, load torque and joint angle in friction models in accordance with dynamic ones, like LuGree and Maxwell models, are to be proposed for precise controller design.

References.

Published papers are included in the resume.