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STATIC ANALYSIS AND STATIC BALANCING FOR PARALLEL MECHANISM IN ROBOTS

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ABSTRACT
Static balancing is a technique to create static equilibrium throughout a certain range of motion. Static balancing for spatially moving parallel manipulators tends to result in considerable added complexity which hampers application. This paper presents a simple static balancing technique for the subclass of translational parallel manipulators such as the Delta robot. Mathematically perfect static balance is achieved without addition of links. Only springs need to be added. The concept and the balancing conditions will be presented. A prototype is being manufactured at the time of writing which demonstrates the feasibility of the concept.

INTRODUCTION
Static balancing is a technique to create equilibrium throughout a considerable range of motion of a mechanism, even in the absence of friction [1]. Static balance is characterized by a constant system potential, regardless of its configuration. In principle, any conservative system can be statically balanced. A common application of static balance is present in gravity equilibration. Gravity balancing has many advantages including reduced operating effort, energy conservation and reduced heat production in actuators, and safety in case of power failure. An overview of gravity balancers using counterweights or springs is available in [1]. It has been shown that any linkage can be statically balanced [2] but practical implementations are largely limited to serial open-chain mechanisms and single-degree-of-freedom closed chain linkages [1]. However, also parallel kinematic manipulators and mechanisms may benefit from static balancing. In parallel mechanisms, static balancing is much less common. Reported strategies include the incorporation of balancers in the legs of parallel mechanisms (‘integrated balancing systems’), or use separate additional legs to house the balancers (‘separate balancing systems’) [3].

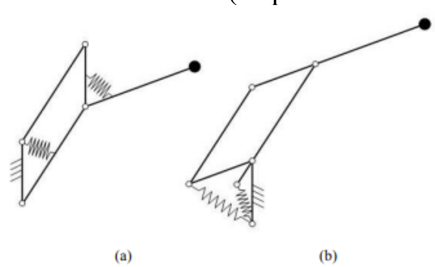

Fig. 1. 2 DOF oen Chains

Some publications on statically balanced parallel mechanisms exist for gravity equilibration [4-7, 15], while [8] reports specific advantages a parallel haptic master device, where mechanical counterbalancing would simplify the controller. Also in cableactuated parallel mechanisms the use of springs is proposed to decrease the effect of gravity in static mode [9]. One evident problem in the reported cases of static balancing in parallel mechanisms is the increased mechanical complexity of the resulting mechanisms. Usually auxiliary links and many springs are added to achieve static balance.

In [3] it is argued that even spatial kinematic mechanisms theoretically need only a single balancing spring or counterweight to achieve perfect static balance, yet for instance in [6] twelve springs are applied. These springs need to have zero free length for perfect static balance, which are hard to obtain or require further mechanical complication.

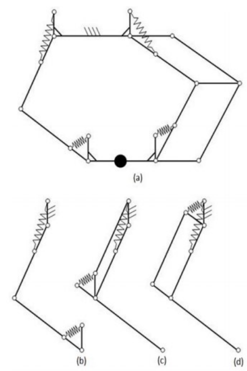

Fig. 2. Planar Translational Platform

More recently, [10] proposed a pantograph mechanism and a counterweight as a separate compensation system to gravity balance parallel mechanisms, where the auxiliary pantograph needs to apply at the center of mass of the moving platform. Also [11] uses a pantograph, this time as an integrated compensation system to dynamically force balance the Delta robot, which implies static balance. Four counterweights and one auxiliary pantograph are needed for perfect gravity equilibration. It therefore remains an open issue to create mechanically simple gravity balancers. This paper proposes a concept for perfect static balancing for a subclass of translational parallel mechanisms, which includes the well known Delta Robot [12], but also more recent Delta-like architectures that use the same type of limbs as the Delta robot. The specific kinematic features are exploited to arrive at simple gravity balancers without auxiliary links. In addition to perfect balancers, also approximate balancers are possible that bring the advantage of the application of normal springs but their presentation is beyond the scope of this paper. The paper is structured as follows. Subsequently, in Section 3 the balancing method is applied to the 5DoF Penta-G robot [13], and simulation results are provided to demonstrate the validity of the concept. Finally, discussion and conclusions are presented.

CONCEPT

Much of the mechanical complexity that is observed in present static balancers in parallel mechanisms is due to the need to create a vertical to attach the springs to (Fig. 1). This vertical may move but needs to remain vertical, i.e. should translate only. In translational mechanisms, this feature of pure translation is inherently present. Therefore it requires no auxiliary mechanism to create the proper spring attachment points: a vertical can simply be attached to the moving platform. This feature can be employed as illustrated in Fig. 2a for a planar example of a 2RRR robot with an auxiliary passive RRR leg complementing one of the driven legs in a double parallelogram arrangement to create the translational behavior of the platform. Each leg is now furnished with two zero-freelength springs. The first one is connected between the base and the grounded links, and the second one between the platform and the floating links. Note that the passive leg is not used to house the springs but purely to create the translational motion. Let us now assume that the center of mass of the platform is on its centerline. Then the mass m is equally distributed between the two active legs. If we then consider one such leg (Fig. 2b), we can rearrange the platform spring such that its potential energy function is not affected by applying modification rules [1]. First the platform spring element is shifted up to the floating joint (Fig. 2c). To maintain the vertical, an auxiliary parallelogram would need to be formed by two added links. As a next step, the spring element is shifted to the base joint (Fig. 2d). To maintain the proper synchronization with the platform, the floating link is extended and one link is added to form a pantograph.

This way, it is shown that the leg corresponds to a well known balancer, i.e. the balanced fivebar also known as the Anglepoise linkage [14], and also known as the parallel type [2]. This shows that the mechanism is gravity balanced from a potential energy perspective. Similarly, it can be shown that the same concept can be applied to the Delta robot. In spite of its more complex spatial motion, the very same balancing spring arrangement applies. Formal proof for the above examples is omitted here because another, similar example will be treated extensively in the next section

APPLICATION TO THE PENTA-G ROBOT

In this section, we will apply the proposed concept to a particular type of delta-like robot, the Penta-G, which is a novel 5 DOF delta-like robot with a configurable platform presented in [13]. This illustrates that the balancing method presented not only applies to the classical delta robot, but also to delta-like robots with configurable platform such as the PentaG, and the par4 robot [16]. Penta-G Architecture The Penta-G belongs to a new class of delta-like robots with configurable platforms. In these robots, the rigid end-effector is replaced by a platform with one or more DOF. The combined actions of the limbs determine the configuration of the platform, i.e. the position and the orientation. In the case of the Penta-G robot, the platform has two DOF and two effectors that form a mechanical gripper. The relative position of the two end-effectors on the platform determines the orientation and the opening of the gripper and the whole platform can move in the three translations.

Consequently, the robot has five DOF, and hence the robot has five actuators, connected via delta limbs to the configurable platform. Each limb has a rotary actuator located on the base and uses a parallelogram unit with revolute joints to keep the orientation of the limb attachment point constant. Each limb has a mobility of 3T1R, the axis of rotation being parallel to the axis of the actuator. The articulated platform is a planar mechanism connected with revolute joints. Two of these links has a finger tip, which forms the two end-effectors of the robot. One of the effector links is directly connected to two limbs. The 2 DOF Configurable Platform of the Penta-G robot The Penta-G robot architecture combines 5 DOF (3 translations, 1 rotation, 1 grasping) in a high stiffness and low inertia structure. This architecture was first developed for haptic applications and then for high-speed pick-and-place applications [13]. In both cases, the total inertia of the device is critical to performance and should be kept to minimum. Since static balancing with counterweights always increases significantly the mass of the system, static balancing with springs is a very promising solution for this type of robot. However, the balancing conditions presented for the PentaG robot do not depend on the 2 DOF configurable platform and the solution is therefore also valid for the par4 (1 DOF platform, 4 limbs [16]) and for the Delta robot (rigid platform, 3 limbs [12]). This is possible because the center of mass of the platform is at a constant vertical distance from the limb attach point at any configuration.

DISCUSSION

The discussed balancer is based on zero-free-length springs. In practice these are hard to obtain, although it is possible to produce them by special coiling techniques and tailored heat treatment [1]. If one chooses to emulate the zero-free-length behavior, for instance with a pulley and string arrangement or other mechanical means, then some mechanical complexity is added to the system, as well as some friction. Due to the springs that are attached to the floating links, these links are no longer loaded in pure tension or compression. This most likely implies that these links need to be reinforced, bringing along some additional mass and inertia. This may degrade the dynamic performance of the robot somewhat. It was chosen to distribute the load of the platform mass equally among the limbs of the manipulator. This results in the least additional load on the links. However, the number of springs is considerable, i.e. 10 in the case of the Penta-G. Due to the translational motion, each point of the platform has the same gravity potential. Therefore the mass can be distributed arbitrarily among the limbs. If one is interested in minimizing the number of springs, for instance, the load can be taken by a single limb, requiring only two springs, regardless of the number of legs.

In the balancers, not only the platform mass but also the link masses, and even the spring mass can be taken into account. The spring mass can be equally distributed amongst its end points [2], and added to the platform or link mass as appropriate. The above issues present a trade-off between static and dynamic performance and will be taken into account in the next phase of this project when building a physical model. In such a model, approximate balancing will be considered which was not presented in this paper but is also feasible. Finally, future work will investigate which of all types of translational platforms are suitable for the proposed balancing concept.

CONCLUSION

A gravity equilibrator system was proposed for a subclass of translational planar and spatial parallel mechanisms, characterized in that no additional links are needed, unlike in known systems. This greatly increases its practical applicability. The proposed system is based on the fact that the non-rotating moving platform provides the proper reference for the spring attachment points, that otherwise need to be constructed using auxiliary parallelograms or similar. In Deltalike robots, it was shown that two zero-free-length springs in each leg can create perfect static balance, while also approximate balancing is feasible. It is intended to build a physical prototype based on the proposed balancer.

REFERENCES

[1] Herder JL (2001) Energy-free Systems; Theory, conception and design of statically balanced spring mechanisms, Ph.D. Thesis, Delft University of Technology, ISBN 90-370-0192-0.
[2] Streit, D. A., Shin, E., 1993, "Equilibrators for planar linkages", Journal of Mechanical Design, 115(3)604/11.
[3] Herder JL (2002) Some considerations regarding Statically Balanced Parallel Mechanisms (SBPM's), Workshop on Fundamental Issues and Future Research Directions for Parallel Mechanisms and Manipulators, Oct 3-4, Quebec, Quebec, Canada.
[4] Jean, M., Gosselin, C. M., 1996, "Static balancing of planar parallel manipulators", Proceedings of the IEEE International Conference on Robotics and Automation, Minneapolis, Minnesota, USA, p3732/7.
[5] Gosselin CM (1999) Static balancing of spherical 3-dof parallel mechanisms and manipulators, The International Journal of Robotics Research, 18(8)819/29.
[6] Gosselin, C. M., Wang, J., 2000, "Static balancing of spatial sixdegree-of-freedom parallel mechanisms with revolute actuators", Journal of Robotic Systems, 17(3)159/70.
[7] Ebert-Uphoff, I., Gosselin, C. M., Laliberté, T., 2000, "Static balancing of spatial parallel platform mechanisms – revisited", Journal of Mechanical Design, 122(1)43/51.
[8] Barette, G., Gosselin, C. M., 2000, "Kinematic analysis and design of planar parllel machanisms acutated with cables", Proc. of the 2000 ASME Design engineering Technical Conferences, DETC2000/MECH-14091.
[9] Baradat, C., Arakelian, V., Briot, S., Guegan, S. (2008) Design and prototyping of a new balancing mechanism for spatial parallel manipulators, J. Mechanical Design, Vol. 130, 072305.
[10] Wijk, V van der, Herder JL (2009) Dynamic balancing of Clavel's Delta robot, Computational Kinematics 2009, Duisburg, Germany, May 6-8.
[11] Clavel, R. "DELTA, A Fast Robot With Parallel Geometry", Proc 18th International Symposium on Industrial Robots (1988), p.91- 100.
[12] Lambert, P., Langen, H., Munnig Schmidt, R. H., "A novel 5 DOF fully parallel robot combining 3T1R motion and grasping", Proc. of the ASME 2010 International Design Eng. Tech. Conferences & Computer and Information in Eng. Conference, August 15-18, 2010, Montreal, Quebec, Canada, papernr. DETC2010-28676 (2010)
[13] Carwardine, G., 1935, "Improvements in equipoising mechanism", UK Patent 433.617, Specifications of Inventions, Vol. 3337, Patent Office Sale Branch, London.

[14] Russo, A., Sinatra, R., Xi, F. (2005) "Static balancing of parallel robots", Mechanism and Machine Theory, 40(2)191-202.

[15] Nabat, V., de la O Rodriguez, M., Company, O., Krut, S., Pierrot, F. (2005) IEEE/RSJ International Conference on Intelligent Robots and Systems, 2005. (IROS 2005). 2005, p553 - 558.