ARM-Z: A HYPER-REDUNDANT MODULAR INSPECTION MANIPULATOR (FOR EXTREME ENVIRONMENTS)

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Abstract

There are several conditions where autonomous inspection robots (due to roughness of the environment), drones (due to high impact sensitivity and inability to operate in vacuum) or classic inspection manipulators (due to reaching problems) can not be used, or their use is not the most effective.
We propose Arm-Z hyper redundant manipulator coupled with camera head for inspection device in extreme environments such as underwater, or outer space. The advantages of the proposed approach are: the length of manipulator can be adjusted, all modules are congruent the control is insensitive to external conditions. The disadvantages are: the control of Arm-Z is difficult and the maximal length of Arm-Z depends on the given conditions. E.g. application in water or non-gravity environments drastically alleviates the problem of Arm-Z length limitations.
This paper discusses the aforementioned issues and presents the preliminary prototype.

1. Introduction

Arm-Z manipulator belongs to a class of hyper-redundant snake-like manipulators. Research on snake robots has been conducted for several decades, especially focusing on mobility. In irregular environments - mountains, trees, water, deserts - bio-inspired snake-like robots in some cases may perform better than the conventional wheeled, tracked and legged forms of robots. Snake locomotion has been studied empirically already in 1940s [1]. 50 years later, the first mathematical model has been developed and snake-like locomotors and manipulators have been proposed in [2]. Today there are many efficient mathematical models of such manipulators and their real-world applications.

Apart from locomotion, snake robots are also present in the field of robotic manipulators (which, using bio-inspired vocabulary, resemble an elephant trunk). The motivation for designing such robots comes from the fact that they can be used in complex environments where using other types of manipulators is impossible. This includes, e.g., medical application with minimally invasive surgery, extreme environment applications: firefighting, urban rescue, disaster relief, and inspection & exploration. Additionally, for example in water, snake-like locomotion in some cases may be more energy efficient than any other approach. It should also be noted that snake-like manipulators often have a relatively large number of degrees of freedom which makes them robust against single module failures. This contrasts with the classic robotic arms with low number of DOFs which are widely used in the industry. For a recent review of snake-like robots, see [3]. Figure 1 locates Arm-Z in the research area.

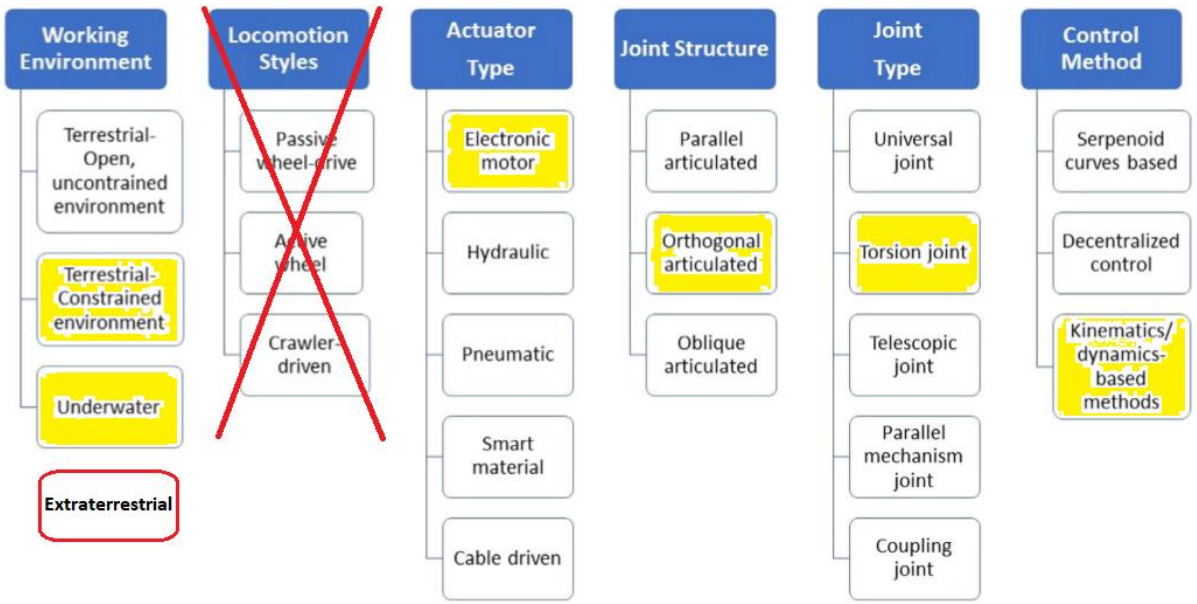

Figure 1. Classification methods of snake robots (figure after [3]). *Arm-Z* belongs to the class of: constrained, various environments, no locomotion, electric motor, orthogonal, torsion joints, kinematic based control manipulators.

Snake hyper-redundant manipulators may be roughly classified into two categories: rigid-backbone robots and continuum-backbone robots. The flexibility of rigid-backbone robots is determined by the number and size of joints. The continuum-backbone robots are made of elastic materials like springs, elastic rods etc. The discussed manipulator is an example of the former.

2. Inspection with snake-like robots

Life extension and maintenance of infrastructure requires routine inspections. Confined and hazardous environments exist in many industries, and new robots are designed to perform inspection and fixing in such places. Remote Access Non-Destructive Evaluation (RANDE) is a testing and analysis technique to evaluate the properties of a component, structure or system for defects without causing damage in spaces with difficult access. For example, the US Air Force air-frames are maintained using the Aircraft Structural Integrity Program (ASIP), where inspection can be done inside wings with snake-like manipulators [4], similar solutions are used by Airbus [5].

The proposed manipulator may be used for purposes of RANDE by equipping it with a proper head. For example, visual inspection tasks would require a camera mounted on a stabilizing gimbal with 2 or 3 DOF.

In order to overcome problems regarding the mechanical stiffness and integrity of the manipulator, applications should be limited to the cases where the number of modules is small (up to 10), or tensions between modules can be reduced. In the latter case, this can be achieved by supporting the or some parts of the infrastructure in which it operates (floor, ground, etc) or operating in an environment like water or cosmic space. Another wide field of applications where stiffness is not a problem, even for a long manipulator, is the field of pipe inspection.

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