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Construction Robot - Based on Inflatable Structure

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Abstract

This paper deals with a new kind of mechanical structure for robotic arm based on elements made of thin, inflatable shells. Our approach offers the advantage of increasing the strength-to-weight ratio of the robot. Moreover, it allows compact packaging and ease of robot deployment, critical in hard-to-reach spaces, where volume and weight are of utmost importance. In addition, the robot is safer due to less damage in case of collision. All those features are basic required characteristics for robots that serve in the building industry so this unique structure specially fits for construction application, and for some other special applications. At this work we test the feasibility of using that new kind of mechanical structure to an practical implementation, painting, by simulation and by operative experiment.

1. INTRODUCTION

In the last decade, the construction industry moved towards more industrial automation like robots (Navon and Warszawski 1992, Seward 1992, Warszawski 1990) and other industrialization methods (Navon et al 1994).

Contemporary robots suffer from several functional problems related to their conventional design, which generally involves rigid links. These problems can be classified as follows:

- Low strength-to-weight ratio,
- High power consumption,
- Cumbersome packaging and transportation,
- Destructive collisions.

The payload-to-weight ratio of contemporary robots is about 1:15, quite low compared with the capability of the human arm, for which the ratio is about 1:1 (Shoham 1986). The demands for speed and accuracy imposed on manipulation tasks in industry have increased significantly in the past few years, imposing stricter requirements on the robots, requiring the use of more powerful actuators and very rigid link; it further increases the weight and the inertia of the manipulator as well as the power required for its operation.

The use of mobile robots raises a new problem, since the volume and weight of conventional robots make them inadequate for transportation. Special restrictions are imposed on robots at the building construction industry (Salomonski 1994), since their volume and weight must be minimized during transportation to the building and from one floor to another; yet, the robots should be able to maintain accuracy while performing in the building site.

Weight reduction results in a more flexible behavior of the robot's arms. Numerous investigations in literature in the last decade, deal with this subject, e.g., (Cannon. and Schmitz 1984, Koren and Shoham 1987, Shoham 1986). However, only relatively few studies deal with the problem of the robot's volume and its mobile capabilities, e.g., (Baldur and Blach 1985, Bridgestone 1991).

This paper describes an experimental robot with light, flexible, and easy-for-deployment structure, based on an inflatable link. Practical implementation of this robot was tested in painting application.

2. THE INFLATABLE LINK

For the present study, a cylindrical-shaped inflatable arm was constructed as a single link of a robot. We thought to minimize the volume of the structure as well as its weight and, at the same time, to simplify packaging and transportation. It was necessary, as well, to achieve acceptable performance during the working phase similar to that of conventional robots.

The proposed mechanical construction for robotic arms is based on structural elements made of thin, inflatable shells, see Fig. 1:

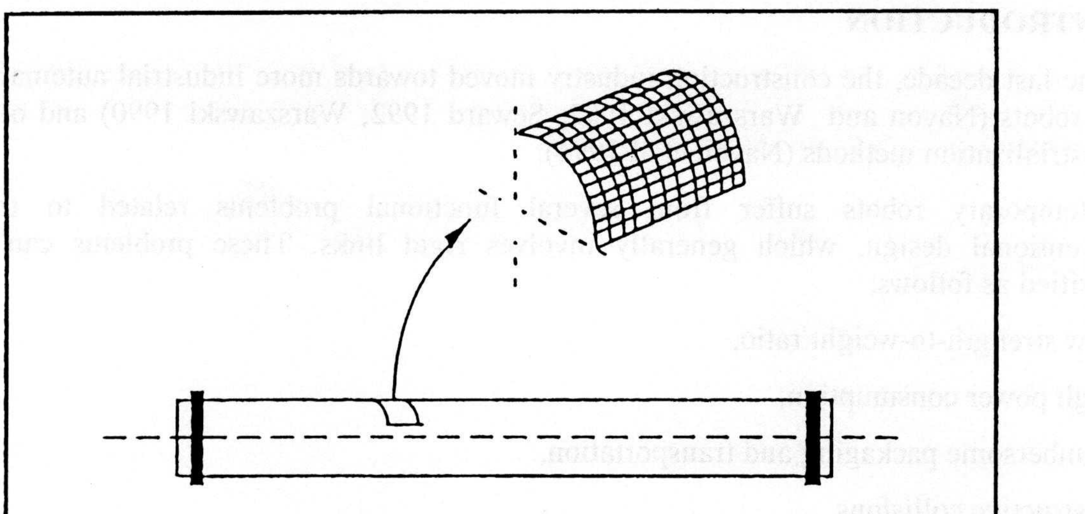

Fig. 1: Inflatable shell and aluminum edges

The shell is made of a composite fabric composed of fiber layers coated by an elastomer matrix. The high flexibility of the fabric allows it to fold without causing any irreversible change, owing to the shell fibers, characterized by low bending and compression resistance. Yet, high tension strength permits the design of a stiff structure by inflating the shell with compressed air, so that the fibers are subjected to preload tension stresses. In this way, the shell can resist compression stresses caused by an external load. The elastomer matrix and suitably designed aluminum edges ensure an excellent sealing, so that the inner pressure is maintained.

3. DYNAMIC BEHAVIOR

To prove the feasibility, a robot link was replaced by our inflatable structure, as illustrate in Fig. 2:

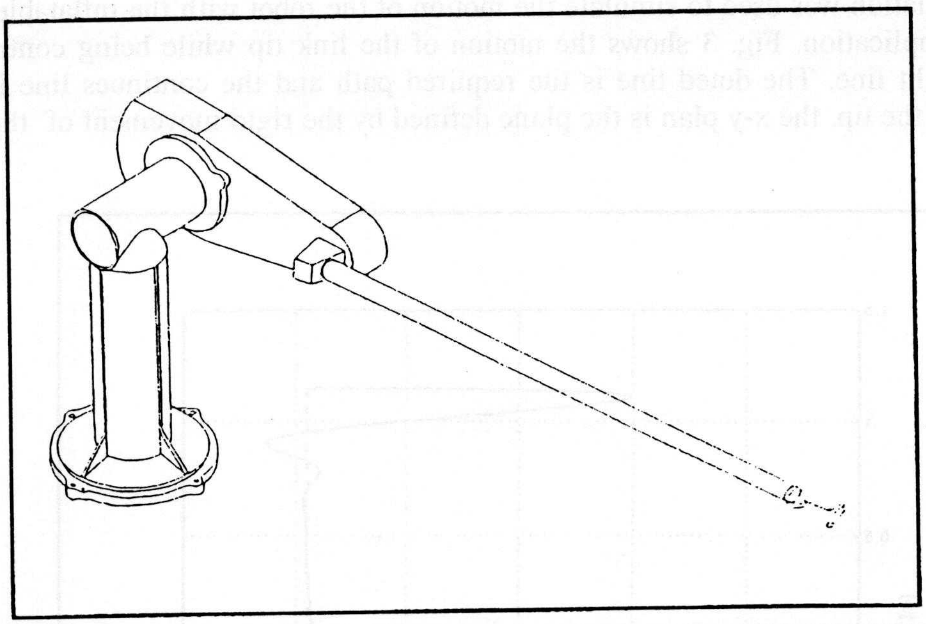

Fig. 2: Modified robot

In order to understand the dynamic behavior of this structure, an analytical model of the inflated link was developed - under the following assumptions (Salomonski 1994, Spector 1989):

- The dynamic response of the inflatable link is similar to that of an isotropic beam.
- The beam bends only in the plane defined by the rigid movement of the last two arms.
- No torsion motion exists.
- Link deflection is small relative to its length.
- The mass at the tip is small and negligible.
- Dissipation is negligible.
- We adopted the Euler-Bernuli model.
- We took into account only the first (and dominant) three modes of motion.

As detailed in (Salomonski 1994), using Lagrange's formulation, the motion equation of the last two links of the robot (rigid and flexible) becomes:

$$M(Q)\ddot{Q}+C(Q,\dot{Q})+G(Q)=\tau$$

Where τ represents the generalized forces (moment at the joints, and zero at the flexible degree-of-freedom along the flexible link), Q represents the generalized coordinate of the robot, M is the inertia matrix, C is the vector of centrifugal and Coriolis torques and G is the vector of potential torques. The specific parameter value of the original robot were based on (Armstrong 1986), and the parameter of the light arm were found by experiment.

The above equation was used to simulate the motion of the robot with the inflatable link in painting application. Fig. 3 shows the motion of the link tip while being controlled along a straight line. The doted line is the required path and the continues line is the actual path of the tip. the x-y plan is the plane defined by the rigid movement of the last two arms.

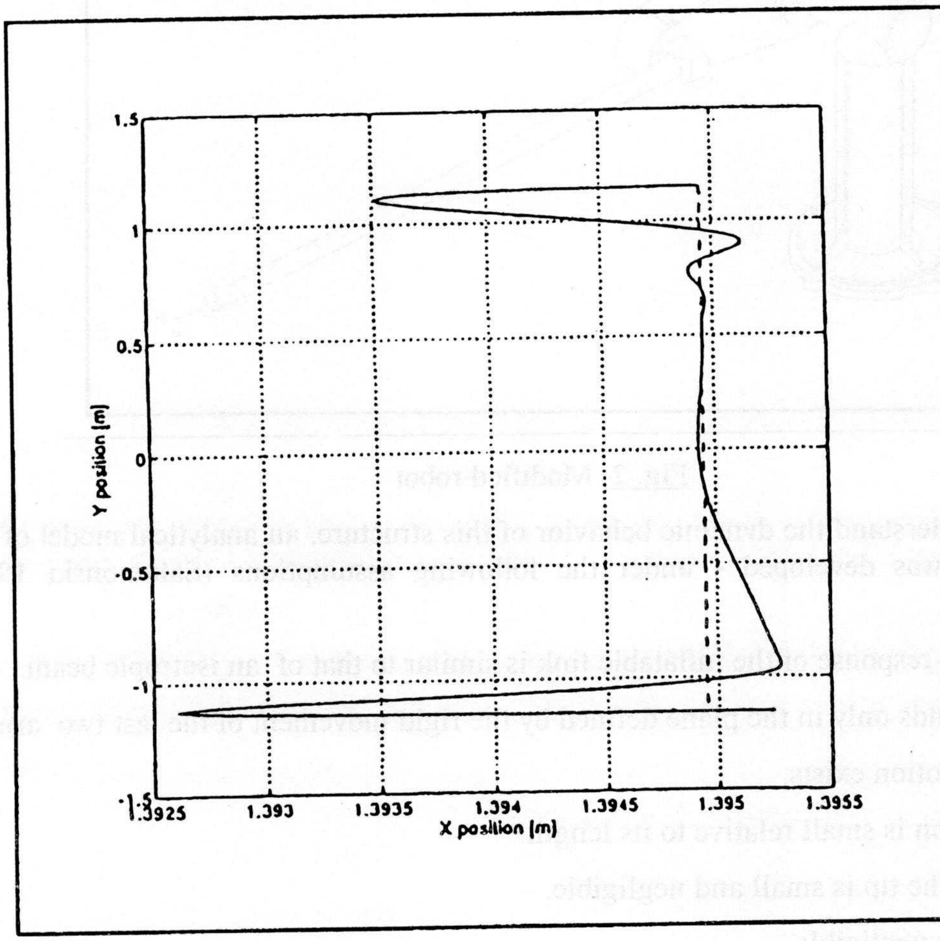

Fig. 3: Motion of the tip along a straight line

The same procedure was repeated for several types of control laws: Computed Torque and Adaptive Control. Common to all controllers is the small deviation of the flexible link tip from the required straight line . This is obtained because of the characteristics of the painting operation. i.e., relatively slow motion of the tip - about one tenth of a meter per sec.

4. THE EXPERIMENTAL SYSTEM

A photograph of the robot is shown in Fig. 4. The manipulator is a modified PUMA robot, whose third link was replaced by an inflatable arm of 1.6m long. The weight of the inflatable arm was approximately as the original arm, but only one-third of the weight. The original controller of the PUMA was replaced by the TRACA controller (Bar-On et al 1991), which is based on four parallel PCs: 386 and 486 based processors. We use that controller to apply different types of control laws to the robot, something we cannot do with the original controller that the manufacturer gave with the robot.

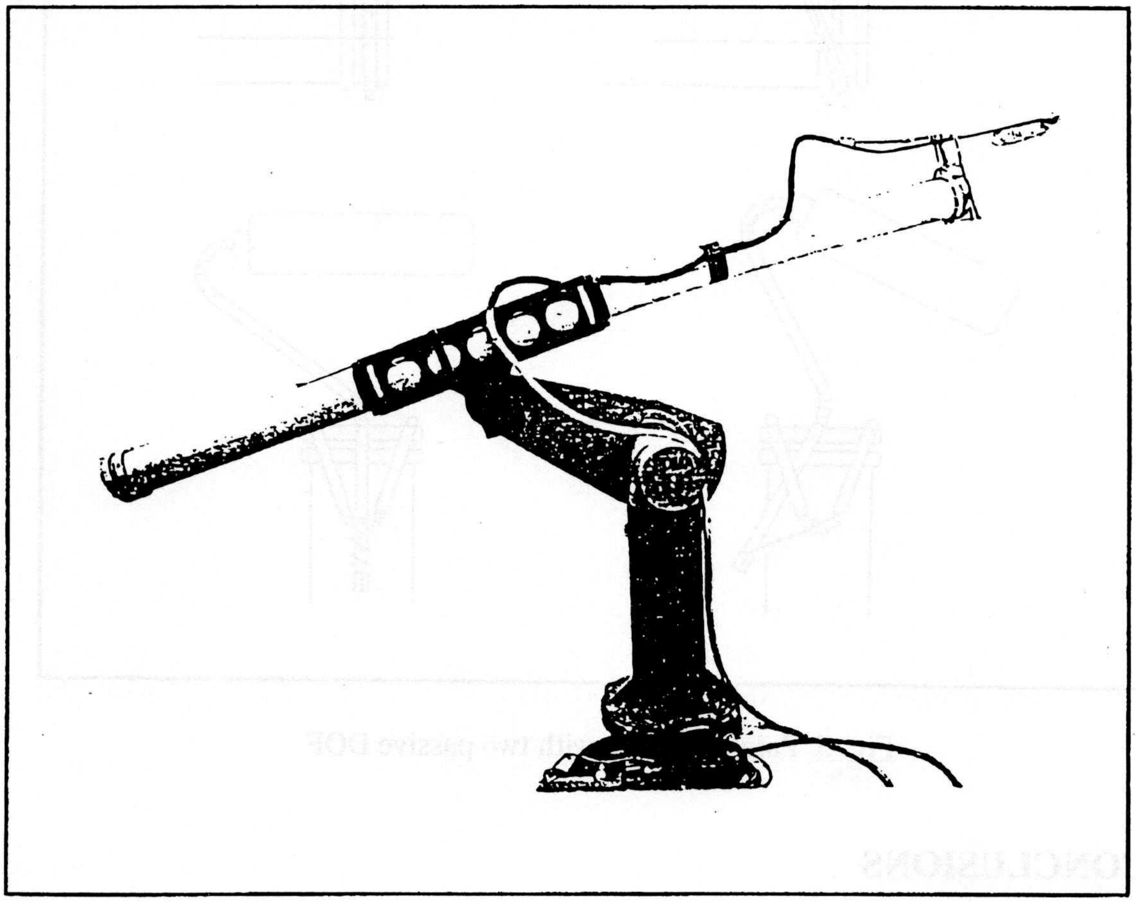

Fig. 4: The robot and the inflatable link

In the experimental system only the first three-degrees-of-freedom (DOF) of the PUMA robot were used. Since for painting applications the tool should normally be aligned with the painted surface, a two-DOF mechanism was built, which can be passively adjusted to the wall (see Fig. 5). Thus, we save activation and control of additional robot's joints.

A painting roller was attached to the distal end of the third link as an end-effector, and the paint was pumped to the roller, in accordance with the robot motion, by a compressor.

The system was tested in painting operations. It has been shown that this system can follow a prescribed trajectory while adjusting to a wall. An evenly cover of painted layer is obtained with only one or two passes of the trajectory.

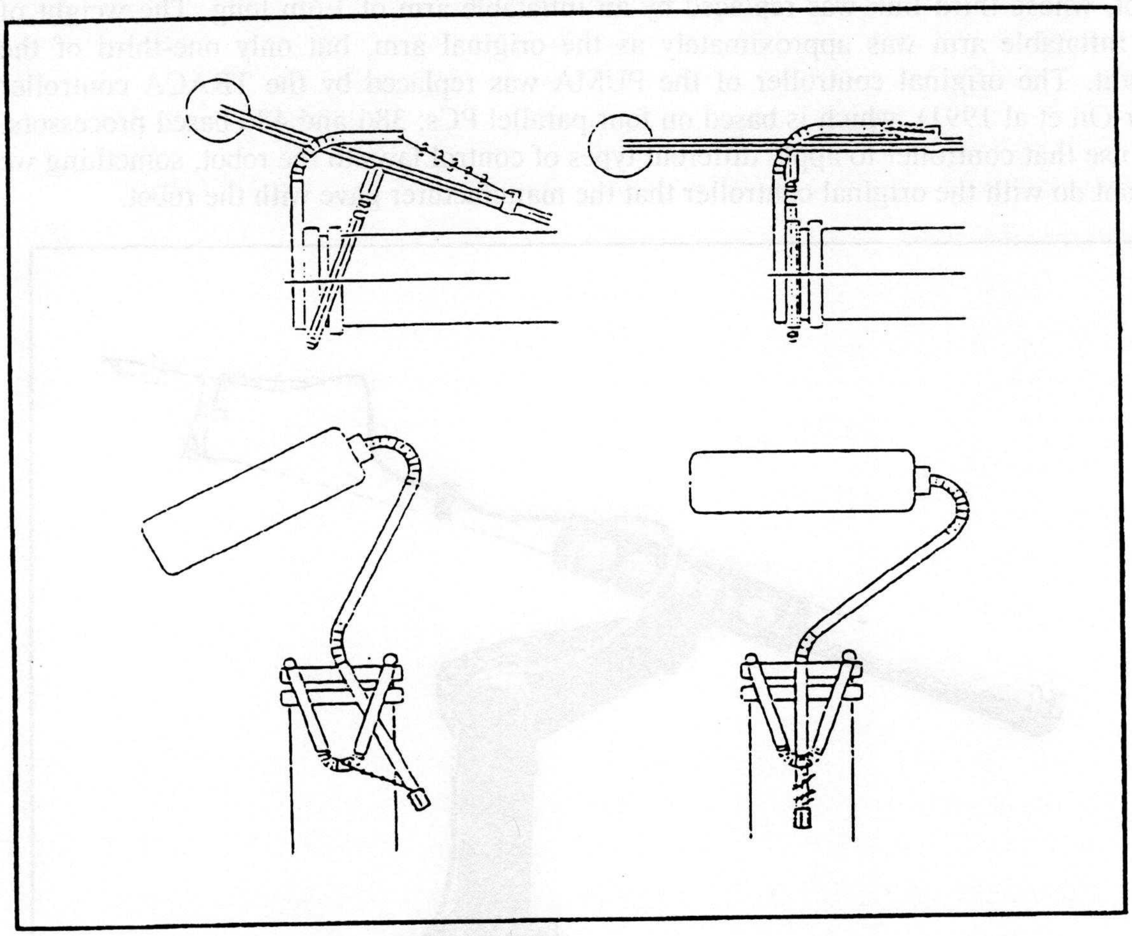

Fig. 5: Painting roller with two passive DOF

5. CONCLUSIONS

This investigation describes a new type of mechanical structure for robotic links, based on inflatable structure. Such structure design improves the payload-to-weight ratio of the robot and allows compact packaging and ease of transportation and deployment. The proposed structure is a thin, inflatable shell made of composite material, retaining its rigidity by the use of compressed air.

Our experimental system, which consists of a PUMA robot with an inflatable forearm, and of a special passive two-DOF device, proves the ability of a system of this type to perform painting applications. It has been shown that an inflatable arm can be of practical use in robotic applications, requiring low weight large work volume, as well as ease of transportation and deployment, and specially fits for construction application.

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