Design and Implementation of a New Discretely-Actuated Manipulator

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Abstract: This paper presents a new 3-D design of a discretely-actuated robot manipulator powered by binary actuators. Binary actuators have two stable states, which are, for example, closed (0) and open (1). Major benefits of this kind of discretely-actuated manipulator are repeatability, relatively low cost, and no need for feedback control. In addition, hyper-redundancy allows tasks to be performed even when some actuators fail. A prototype of the new 3-D design is presented in this paper.

1. Introduction

Continuously-actuated robotic manipulators are the most common type of manipulators even though they require sophisticated and expensive control and sensor systems to increase their accuracy and repeatability. Discretely-actuated robot manipulators are potential candidates to be used in applications where high repeatability and reasonable accuracy are required. Such applications include pick-and-place, spot welding and assistants to people with disabilities.

A new design concept for this kind of manipulator in the spatial case is presented and hardware is demonstrated. The concept of a 3-bit planar binary Variable Geometry Truss (VGT) module is used in this implementation. Figure 1 illustrates all possible configurations of a 3-bit planar binary VGT module. The new design is developed from a

2-dimensional binary-actuated VGT manipulator and a 3-dimensional binary-actuated Stewart-platform-like manipulator which were previously designed and built by the authors and co-workers (shown in Figure 2 and 3 respectively). The new design uses 3-bit binary VGT modules stacked on top of each other with a discretely-actuated rotating joint between each module. As a result, the manipulator has the ability to reach many points and covers a full 3-dimensional sphere around the manipulator itself.

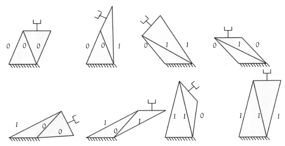

Figure 1: Eight-possible-configurations of a 3-bit binary VGT.

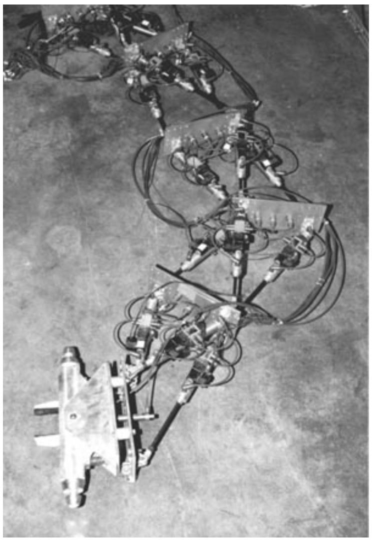

Figure 2: A 2-D binary VGT manipulator

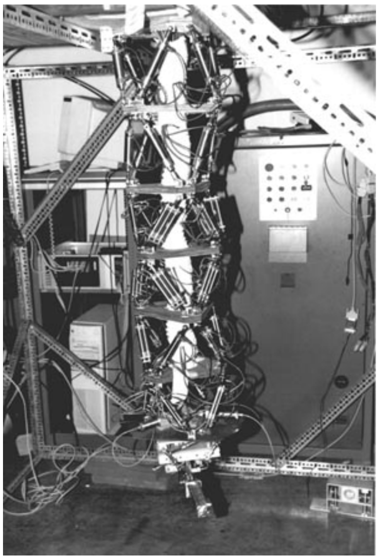

Figure 3: A spatial binary Stewart-platform-like manipulator.

2. Previous Work

Because of the high cost of traditional continuous manipulators with sophisticated sensing and control systems, a number of reduced complexity systems have become popular. Canny and Goldberg [1] discussed a reduced complexity paradigm for robotic manipulation. Furthermore, researchers such as Mason, Erdman and Goldberg have presented reliable sensorless manipulation schemes (See e.g. [2], [3] and references therein). A binary hyper-redundant manipulator is one kind of discretely-actuated manipulator. This manipulator does not require sensors or feedback control systems, which reduces its cost. Our concept of a binary hyper-redundant manipulator was influenced by research on snake-like robots [4], [5] and the design of variable geometry truss (VGT) manipulators [6], [7], [8]. One of the authors presented the concept of the binary manipulator in [9]. There have been several improvements in this manipulator concept. A planar binary VGT manipulator and a spatial binary Stewart-platform-like manipulator were designed and built by one of the authors and co-workers. The planar binary VGT manipulator consists of five modules of 3-bit binary VGTs stacked on top of each other. This manipulator has the ability to fold back to reach its own base. The spatial binary Stewart-platform-like manipulator consists of six modules of 6-bit binary Stewart-platforms stacked on the top of each other. Each module has $2^6 = 64$ configurations (a total number of 68.7 billion configurations for the whole manipulator). This 3-dimensional binary manipulator has a very limited hemispherical workspace. This problem occurred because of the structure of each Stewart-platform-like module. A number of papers present forward and inverse kinematics techniques and control for this kind of manipulator ([10], [11], [12], [13], [14], [15], [16]).

3. Design

The new manipulator design produces a hemispherical workspace. We have built a full size four-module prototype of this new 3-D manipulator using two-state pneumatic actuators. Furthermore, we have designed a new kind of discrete rotating joint controlled by three binary actuators.

3.1. Design of a discrete rotating joint

We have designed a discrete rotating joint using three binary actuators to control the angle and direction. We use a set of three gears. Two of these gears are mounted along with two rotary actuators on the base and the third is mounted on the turned module. One of two rotary actuators is used as a fluid-filled damper in order to decrease speed and reduce vibration. A series of holes aligned in a circular pattern on the turned module (rotor) acts as the position controller. While the rotary actuators and gear set are in operation, we use a compact linear binary actuator located between the base and rotor as the stopper. A cone shape is attached to the tip of the actuator, which is inserted into each hole to stop the rotor. The base and rotor are shown in Figure 4.

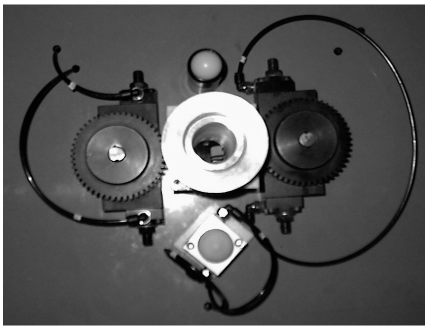

Figure 4 (a): A rotary joint comprising a rotary actuator, a rotary dashpot, linear actuator and a gear set.

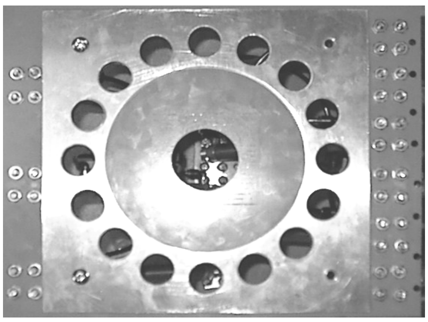

Figure 4 (b): A circular set of holes on the turned module (rotor).

3.2 Design of a new spatial binary-actuated manipulator

This design is influenced by the advantages and disadvantages of the previously built binary manipulators. The new design uses 3-bit binary VGT modules stacked on top of each other with a discretely actuated rotating joint between each module. Figure 5 illustrates some configurations of five concatenated modules. We have built a full size prototype using two-state pneumatic actuators. The prototype consists of three 3-bit binary VGT modules with discrete rotating joints between the modules. PC interfacing with a relay switchboard triggers the solenoid valves, and controls each actuator. In order to reduce the vibration occurring due to the high speed of the pneumatic actuators, dashpots have to be introduced in parallel to the actuators in each module.

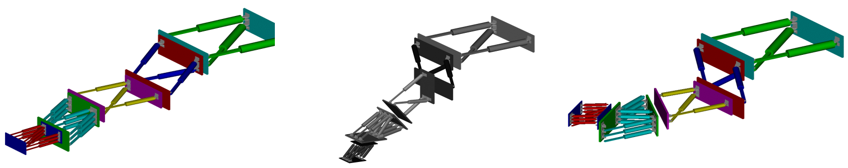

Figure 5: Configurations of a five-binary-module.

4. Experiments and Results

The kinematics were successfully simulated before the prototype was built. A 3-bit planar VGT module has eight 2^3 possible reachable points. Therefore, the new discretely actuated manipulator can reach $2^{(3xN1)\ x\ (N2\ x\ N3)}$ points. N1 is the number of 3-bit binary VGT modules, N2 is the number of rotating joints, and N3 is the number of states in each joint. We have built and tested the prototype manipulator. The load-bearing capacity of the manipulator depends on the actuators available on the market. Overall the experiments with the manipulator were very successful in demonstrate the range of motion.

5. Conclusion and future work

The results were very satisfactory. We have solved the vibration problem by using dashpots in parallel with the actuators in each module and each rotating joint. Figure 6 illustrates some configurations of the new spatial binary actuated manipulator. Attempts are currently being made to improve the performance of the structure and the rotating joints. We are interested in using a commercial magneto-rheological fluid, which is a kind of oil with magnetizable particles, to be filled in the dashpots to be placed in parallel with the actuators in each module. In this case, we will be able to control the stop positions by using electromagnetic systems, which will provide more states than a regular binary actuator. Our further experiments shall involve implementation of a new inverse kinematics algorithm [17].

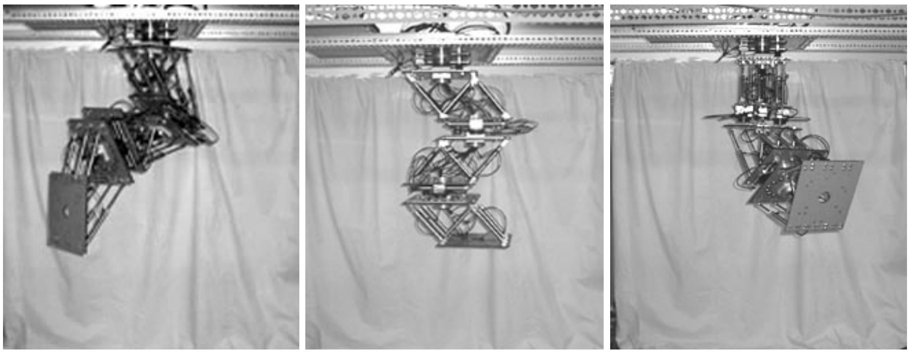

Figure 6: Configurations of the new spatial binary actuated manipulator.

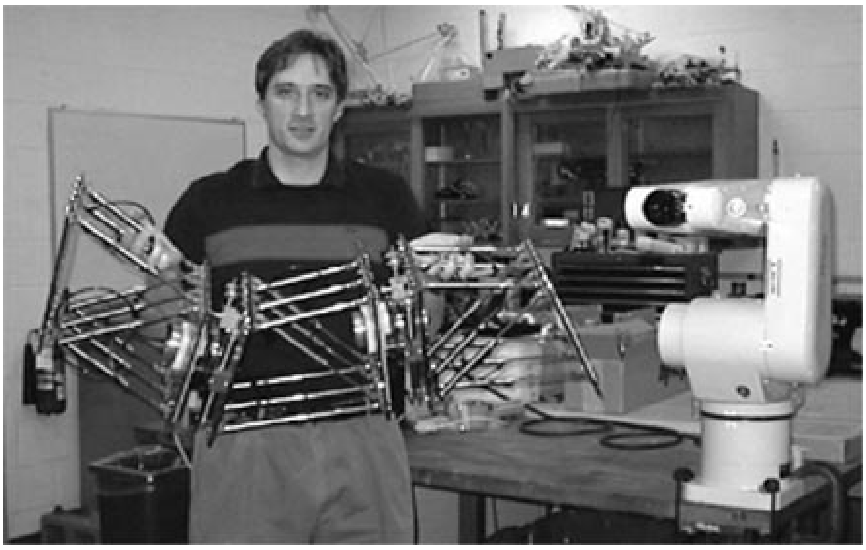

Figure 7: The light weight of the new manipulator is illustrated in comparison with traditional manipulators.

Acknowledgment

The authors would like to thank Mr. David Stein for design suggestions. We are also gratefully thank to Mr. Zheng Xu, Mr. Yong T. Kwon and Mr. Dory T. Lummer for their valuable technical assistance.

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