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Intuitive Control System for Cable-Driven Robot Manipulator

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Abstract – The presented controller system has been designed and dedicated to the intuitive and instinctive cable driven robot manipulator. The described robot manipulator is the moving platform suspended by the set of six variable-length steel cables. In practice the construction is like a standard inverted Stewart platform - the platform is able to move in all six degrees of freedom with respect to its base. The presented manipulator has been equipped with the suspending base that has been adequately improved. The improvement gives the additional 3 degrees of freedom and it allows to effectively increase the operation ability of the manipulator in small workspaces. The cable robot can be employed as the master-slave system useful for various teleoperator tasks

1 Introduction

There are many extremely dangerous work environments, especially for people's life and health. For example, the situations are in different laboratories where radioisotopes, chemicals and harmful biological substances are present. Of course the special safety standards and procedures are applied in each workplace to protect the workers from health hazard. Sometimes the workers must be dressed in special-purpose overalls, gloves, masks, safety glasses and so on. The simple arrangements can not be good enough. Moreover, the use of protecting overalls can often be very handful and even simple operations can become very time consuming.

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Only the implementation of autonomous or teleoperator systems allow for total elimination of danger for staffs employed in hazardous workspaces.

Below the simple robotic system is presented. It has been designed and dedicated to the tasks generally performed in small academic research laboratories [1]. The system allows for remote handling of various objects. The human operator can be fully separated from the work field where the operations on the objects are done. The system can be employed in one of two modes as needed. One of them is robotic autonomous mode and the other one is the teleoperator mode [2, 3]. In this paper we have presented the use of the system as the teleoperator manipulator. The mode allows for performing all kinds of manipulations in real time at a distance, well isolated from the workplace if required. The adequate controller tool is needed that can drive the teleoperator manipulator correspondently to the instinctive and intuitive movement of a hand of the system's operator.

2 6-DOF cable manipulator

There are a lot of commercially available robotic manipulators – the most often different manipulator arms are offered. Usually the base of the manipulator arm is not moveable. Thus the workspace of the "static" robotic arm is relatively small. Of course, there are robotic arms equipped with moving bases but usually the units are very expensive. The use of the cable-driven manipulator can eliminate the considerable disadvantage and the manipulator is relatively simple and low cost.

The robotic crane, invented and developed at National Institute of Standards and Technology (NIST) called RoboCrane® is a classic example of the very effective cable manipulator [4–8]. In practice, the RoboCrane® is an inverted Stewart Platform [9] - a set of six cables is used instead of struts. The octahedral cable construction is astonishingly stiff and it has robustness for different disturbances [8]. The flying platform is the main part of the manipulator – see Fig. 1.

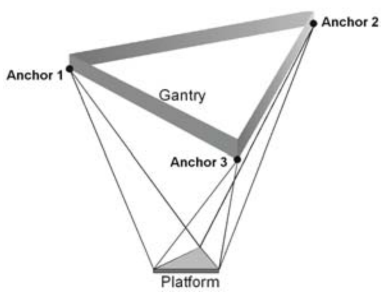

Fig. 1. The scheme of the construction of 6-DOF cable-driven manipulator – the inverted Stewart platform.

The manipulator platform has the form of the equilateral triangle. Each vertex of the triangle is suspended by the two cables which run to the anchors. The gantry above the manipulator is the "inverted" base of the cable manipulator. The anchors are placed in the vertices of the

equilateral triangle located on the base. In this way the platform uses gravity only to maintain tension in cables. The set of six variable-length cables allows to adjust position and orientation of the platform with respect to the base. The manipulator has six degrees of freedom – there are three position coordinates in the 3D Cartesian space and three rotation angles: pitch, roll, and yaw.
Following the example of the NIST design, we have proposed the somewhat modified version of 9-DOF cable driven manipulator.

3 Construction of 9-DOF cable manipulator

The construction of the considered cable driven manipulator is as follows. The platform has the form of the circumscribed circle about the equilateral triangle. Each vertex of the triangle is suspended by the two cables which run to the spinning wheels (the anchors) located on the top of the cubic aluminum gantry. The top view of the described construction is presented in Fig. 2.

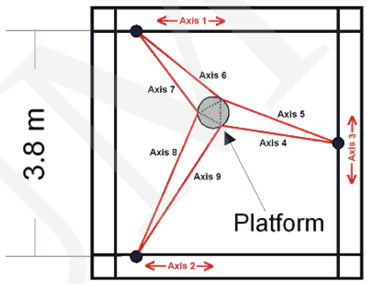

Fig. 2. The top view on the 9-DOF cable manipulator.

The cables attached to the platform are pulled by six separate winches driven by electric motors that can extend or retract the cables. In this way the required position (x_1, x_2, x_3) and orientation (**P**itch, **R**oll, **Y**aw) of the manipulator platform can be fixed by the proper reducing or extending the lengths of the cables. It provides the six degree of freedom for the manipulator.
The cables suspending the platform run to the winches via the spinning wheels – (pulleys) placed on the mobile boards – see Fig. 3 and 4. In this way the anchors of the manipulator base can be moved along the axes: X_1, X_2, X_3. Thus the presented manipulator system has been enhanced by additional three degrees of freedom.
The construction of the base gantry is adapted to install three special guide rails X_1, X_2, X_3, each for one carriage equipped with two bearing pulleys. The carriages (boards) are mechanically powered by the chain drives and the bearing pulleys can be moved along guide rails.
It has been done to improve navigation of the platform in dynamic change environments. In other words, the triangle of the anchors suspending the platform can be reconfigured as only needed – for example, the suspending cables can omit obstacles.

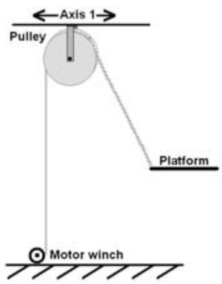

Fig. 3. The scheme of the construction of 6-DOF cable-driven manipulator – the inverted Stewart platform.

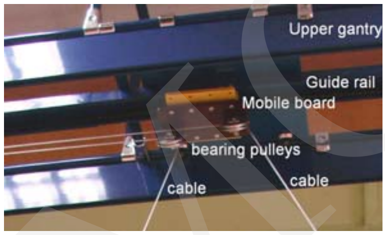

Fig. 4. The photo of the gantry with the mobile mechanism including the couple of bearing pulleys for two cables supporting the manipulator platform.

The manipulator platform is controlled by nine electric motors: six winch motors that control the lengths of the cables and three motors that change the positions of anchor points.

Fig. 5. The photo of described cable-driven manipulator.

All the motors and electronic equipment are incorporated into the gantry – see Fig. 5. The motors are equipped with incremental decoders. They are interfaced with the autonomous PID controllers linked to the PC. It allows to control the lengths of the suspending cables and the positions of the anchors. Fig. 6 displays the architecture of the electronic system employed to control the manipulator [10, 11]. The control process is supervised by a PC computer equipped with MS Windows operating system and special dedicated software.
The rules of the control process are simple. The lengths of the cables suspending the platform are calculated applying the inverse kinematic equation [12]. For the calculations the Cartesian coordinate frame has been defined and it is related to the base gantry. In other words, the

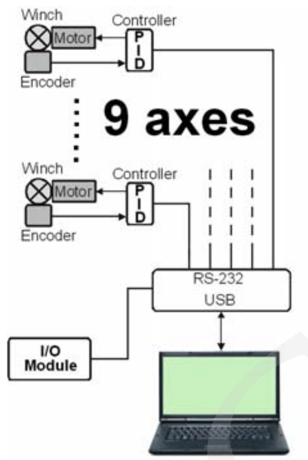

Fig. 6. The architecture of the main part of the electronic control system for the cable driven manipulator.

calculated lengths of cables are determined for a given position (x, y, z) and orientation (Y, P, R) of the platform and for given positions (x_1, x_2, x_3) of the anchor points in the defined coordinate frame including our cubic workspace.

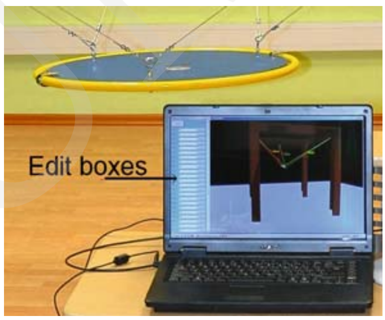

Fig. 7. The photo of the computer screen with the visualization software of the manipulator workspace.

When any changes of the position and/or the orientation of the platform are desired, then only new lengths of the cables must be estimated.
The autonomous PID controllers physically make the proper changes of the cable lengths. For the operations we have the special visualization on the computer screen – see Fig. 7. The software visualization (called ”VirtMan”) displays the scheme of the workspace frame and edit boxes for a set of parameters, such as for example a desired new position (x, y, z) of the platform, the velocity (v_x, v_y, v_z) of the movement to the new position, and many others. It is a direct way for the operator of the system to control the described manipulator. However, it is not an intuitive or instinctive manner for easy manipulations of the platform, especially executed from a distance when the workspace is watched by a video camera.

4 Intuitive control system

The intuitive system for driving the platform movement is wanted. It is specially required for the operator to use the described manipulator in the teleoperator mode at a distance from the workspace. For the purpose the proper device is needed, that should give straightforward natural hand control resulting in the movements of the platform corresponding to the instinctive or intuitive gestures of the hand of the operator. The most often the trajectory of the platform motion is three dimensional. Thus the natural solution for driving the platform is application of a control device which allows users to navigate in 3D space.

The presented driving system is based on the commercially available input device called ”Phantom Omni® Haptic Device” – see Fig. 8. The tool has been employed as a 3D joystick.

Fig. 8. The PHANTOM Omni® haptic device.

To be exact the tool is equipped with the special stylus that features 6-DOF positional sensing in the cuboid space – Width = 160 mm, High = 120 mm, Depth = 70 mm. The stylus tip is gimbaled and it is able to detect Yaw, Pitch, Roll and angles with about $\pm$ 5% linearity. Moreover, the haptic provides the sense of touch (tactile) by generating force feedback up to the maximum value about 3,3 N. It is enough to employ the device as the instrument for the operator to control the manipulator. We tested the system with the haptic controller (see Fig. 8) both in the teleoperator mode and for the on-line programming process to teach the robot different sequences of operations which can be next repeated automatically.

A general idea of the use of the haptic controller is that the space and angle coordinates are read out cyclically from the haptic. They are transferred to the proper edit boxes of the VirtMan program – Fig. 7. The rate of the operator's gestures is also taken into account and analyzed. Next according to the rating, the platform velocity is calculated and displayed into the appropriate edit boxes. Of course, the platform moves consequently to the displayed parameters.

The velocity of the platform is limited by the capabilities of the servomotors. It is possible that the operator could demand too high movement rate by means his hand motion. Then the operator is informed that intentional movements are too fast by force feedback - feeling the resistance of the stylus.

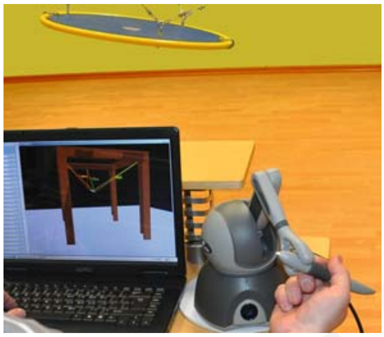

Fig. 9. The control of the cable manipulator system by means of the haptic.

5 Conclusion

The performed tests show that the described control system is very intuitive and it does not require specially long training to effectively control the cable driven manipulator. It is especially convenient in the teleoperatore mode.

6 Acknowledgment

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