Development of a Teleoperative Quadrupedal Manipulator

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***Abstract*—This paper outlines the design and operation of a teleoperated quadrupedal robot enhanced with a manipulator arm and gripper. Using the mobile quadruped platform Laikago, a ViperX 300 robot arm and a wearable inertia based motion capture system, a low-cost robot was assembled capable of hybrid robot and manipulator control to allow seamless and intuitive human to robot interface. Vision for the user is provided through a 3D camera mounted at the front and a stereo camera mounted on the robot arm end-effector. The robot is fully controllable using a wearable inertial based motion capture suit. To verify the functionality of the whole system prior to testing on the real robot, physical simulations were conducted and successfully demonstrated the capabilities of the proposed teleoperation framework.**

***Index Terms*—quadruped robot, manipulator, legged robot, teleoperation**

I. Introduction

Teleoperation has been an important aspect of robotics as it allows for tasks that require the accuracy of a human operator to be completed whilst forgoing the need of having the operator be physically present. The benefits of teleoperated robotics extends to tasks that are also too dangerous for humans to be present as well as for tasks that are located in impossible or difficult to reach environments.

The extent of legged robot teleoperation has typically consisted of a simple joystick, however, when a legged robot must complete complex manipulation tasks, there lacks an intuitive control method able of allowing a difficult task to be completed in a short time frame with minimal errors. Existing legged robots such as the ANYmal have demonstrated that it is possible to combine a robotic arm and a quadruped platform to perform simple manipulation tasks [1]. However, performing these tasks requires the operator to switch between controlling either the quadruped robot or the arm, which would result in difficulty when dealing with complex situations. A method of overcoming this issue has recently been shown using the Boston Dynamics Spot and dynamic grasping [2]. This method however cannot be used for complex or delicate tasks that require teleoperation due to the degree of automation used.

A solution to this is to adopt a different control method that allows for a wider range of human input. A method that has been explored is the use of Inertial Measurement Unit (IMU) motion capture to control robots. Several insights have shown that it is possible for both the high and low level control of a robot to be generated through the use of various IMU embedded devices to a high enough degree of accuracy required for manipulation. One example is the use of an wearable inertia based motion capture system to control the high-level walking motion of a bipedal robot where the commands stemmed from the feet positions [3]. Another example is the use of gesture controls from hand and arm mounted IMUs to control the high-level motions of a wheeled robot [4]. Through the use of an arm-mounted IMU-embedded device, a 7 Degree of Freedom (DoF) robot was reliably teleoperated [5]. The use of teleoperation and the accuracy and robustness of a wearable inertia based motion capture system is demonstrated thoroughly through the development of a dementia-care robot [6]

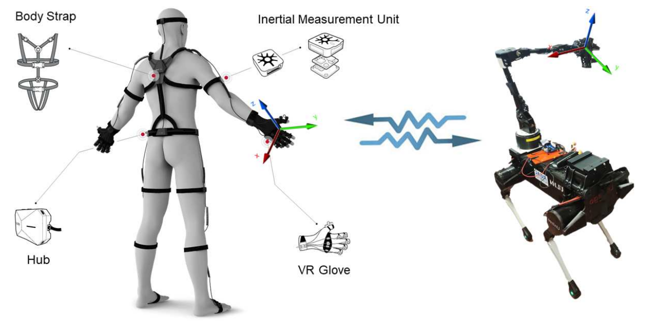

Fig. 1. The developed teleoperative system consists of a wearable inertial motion capture suit (left) and a quadrupedal manipulator (right).

As illustrated in Fig. 1, the developed teleoperative system is composed of the wearable inertia based motion capture system which is worn by the operator and the quadrupedal manipulator, of which is composed of the ViperX 300 robotic arm and the Laikago quadruped robot. The Laikago from Unitree is a medium size, low-cost quadrupedal robot capable of locomotion via a single trotting gait. The ViperX 300 is a light-weight 5 DoF robotic arm. The need for a higher DoF robot arm was alleviated due to the extra DoF gained by the legged mobile platform. There were no visual sensors mounted on the original Laikago or robot arm. In this paper, the control system allowing the wearable inertia based motion capture system to communicate with the teleoperative system will be outlined along with the simulation test results. The fully developed system will allow the operator to control both the quadruped robot and the manipulator simultaneously.

II. Hardware Overview

A. Hardware Design

The main goal was to minimise the extra load caused by mounting the arm on the Laikago to ensure locomotion is as

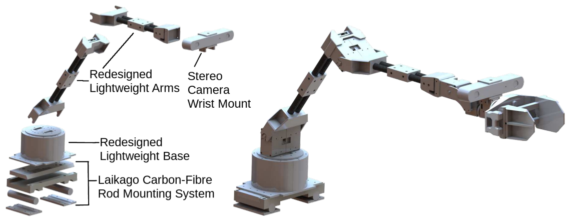

Fig. 2. Labeled exploded view (left) of the redesigned and additional parts assembly, and (right) whole robot arm assembly.

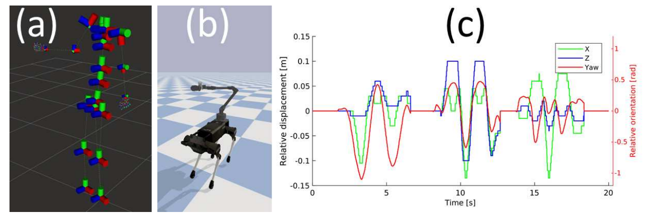

Fig. 3. Teleoperation validated in simulation[1]. (a) Sensed human model. (b) Simulated quadrupedal manipulator. (c) Relative pose sent to the robot.

stable as possible and also to provide enough sensory data to make operation easier. To make the robot arm more suitable for mounting onto the Laikago, the base was redesigned to be more compact and the aluminium box-section lengths of the arm were replaced with carbon fibre rods. These changes reduced the overall weight of the arm from 4.1 kg to 2.6 kg. The Laikago possesses two parallel carbon fibre rods as mounting locations where two 3D-printed parts could fix the robot arm and the 3D camera to the Laikago. A 3D camera is mounted on the front of the Laikago, on top of the onboard computer, allowing the user to have a wide field of vision when teleoperating the robot. A stereo camera is mounted on the modified wrist link of the end-effector. The 3D camera will allow the teleoperator to assess the surroundings of the robot and allow for safer locomotion without the need of moving the robot arm to gain visual feedback. The stereo camera output will allow for manipulation tasks which require a greater degree of accuracy to be performed, such as cutting wires or carrying liquids. A labelled diagram of each redesigned part and mounting system along with a rendered full assembly of the robotic arm is illustrated in Fig. 2.

B. Teleoperation Control System

The human body motion is captured by a wearable motion capture system, Perception Neuron, which provides stable and accurate human body segments pose estimations. The accompanied SDK could read whole skeleton data including fine finger movements and broadcast to ROS through *rosserial* protocol. Since the human master and the robot are kinematically dissimilar, therefore, directly connecting them at joint levels is not feasible. Relative scaled pose is then connected between the human hand and the robot gripper, where at time t, their relation is described as

$$\boldsymbol{x}_{sd}^{t} = \boldsymbol{x}_{sd}^{0} + \boldsymbol{\mu}(\boldsymbol{x}_{m}^{t} - \boldsymbol{x}_{m}^{0}), \tag{1}$$

where $\boldsymbol{x} = [x, z, \theta_{\text{yaw}}]$ are the (x) sagittal and (z) vertical displacements and (θ_{yaw}) rotation about the vertical axis, subscripts "m" refers to the master, "s" to the slave, and "d" to a desired value. Superscript "0" refers to the initial timing where both end effectors are connected. We use the VR gloves' readings to detect the hands' closures as the trigger to move the robot. Specifically, the left glove's closure triggers the left hand movements for controlling the legged mobile base, and the right glove's closure connects the master's right hand to the gripper. $\boldsymbol{\mu}$ is used to scale the motions between the master and the robot. Note that the orientation is not scaled, thus $\mu_{\text{yaw}} = 1$.

III. Simulation

To validate the developed teleoperative robotic system, we firstly performed simulation studies. A customized URDF was created that combines both the Laikago and ViperX 300 models and loaded into PyBullet [7], the Python bindings of the widely used physics simulation engine Bullet. With this environment, the feasibility of the control schemes and performance of the robot could be accurately judged. The Laikago's walking pattern generation is adopted from a bipedal gait generator [8] and the legged manipulator's joint commands are solved using a QP-based whole body controller [9].

As a proof of concept, the initial simulation was carried out only for teleoperating the robot arm while the quadruped was walking in place. The results are shown in Fig. 3. The human master was moving only the right arm about the vertical axis and along the front, vertical directions, respectively. The relative pose from the motion capture data was sent to the robot only during the master's right hand was closed. This strategy is quite intuitive and its successful enabling and disabling of the robot arm's motion can be seen from Fig. 3(c). We could also observe that, though the human master endeavoured to move every time along only one direction, there were inevitable coupled motions sent to the robot. Extra effort is needed to improve this for fine operations.

IV. Conclusion

A robot capable of seamless teleoperated movement and manipulation with the use of a wearable inertial motion capture device is presented. The hardware layout and design of the overall robot was discussed along with modifications to optimise the robot for teleoperation. The robot was thoroughly tested in a simulation environment. The wearable inertia based motion capture system was shown to be a robust method of controlling the robot in a seamless fashion. The robot was shown to be capable of performing teleoperated tasks from within the simulated environment. Further work includes the fully finished assembly of the robot in real life, along with real life testing through various manipulation scenarios.

[1] Video of Fig. 3 is available at https://youtu.be/J8xHjMD8-vA/

References

[1] C. D. Bellicoso *et al*., "ALMA - Articulated locomotion and manipulation for a torque-controllable robot", International Conference on Robotics and Automation, Montreal, QC, Canada, 2019, pp. 8477-8483.

[2] S. Zimmermann *et al*., "Go Fetch! - Dynamic grasps using Boston Dynamics Spot with external robotic arm", IEEE International Conference on Robotics and Automation, Xi'an, China, 2021.

[3] S. Kim *et al*., "A walking motion imitation framework of a humanoid robot by human walking recognition from IMU motion data", IEEE-RAS International Conference on Humanoid Robots, Paris, France, 2009, pp. 343-348.

[4] S. Shin *et al*., "Controlling mobile robot using IMU and EMG sensor-based gesture recognition", International Conference on Broadband and Wireless Computing, Communication and Applications, Guangdong, China, 2014, pp. 554-557.

[5] C. Yang *et al*., "Neural learning enhanced teleoperation control of Baxter robot using IMU based motion capture", International Conference on Automation and Computing, Colchester, UK, 2016, pp. 389-394.

[6] H. Lv *et al*., "Teleoperation of collaborative robot for remote dementia care in home environments", IEEE Journal of Translational Engineering in Health and Medicine, vol. 8, pp. 1-10, 2020.

[7] Erwin Coumans and Yunfei Bai, "PyBullet, a Python module for physics simulation for games, robotics and machine learning", http://pybullet.org, 2016–2021.

[8] C. Zhou *et al*., "Overview of gait synthesis for the humanoid COMAN", Journal of Bionic Engineering, 14(1), 2017, pp. 15–25.

[9] C. Zhou *et al*., "A Generic optimization-based framework for reactive collision avoidance in bipedal locomotion", IEEE International Conference on Automation Science and Engineering, pp. 1026-1033, 2016.