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Teleoperation of a Legged Manipulator for Item Disposal

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***Abstract*—With teleoperation currently being the optimal method of controlling legged robots in real world applications, there presents the demand for a teleoperation framework offering extensive functionality. As such, this paper presents a teleoperation framework that, with the implementation of a set of teleoperation strategies, enables a teleoperator to control the gripper, trunk and front left (FL) foot frames of a legged manipulator while utilising the robot's redundancy through the use of a Whole-body controller (WBC). This enables the teleoperator to utilise these frames to complete real world tasks, as demonstrated in this paper with the teleoperation framework being used to dispose an item in a push peddle bin.**

***Index Terms*—whole-body control, legged manipulator, teleoperation, quadruped robot**

I. INTRODUCTION

In recent years, legged manipulators have seen increased use in industry due to their ability to traverse a world rich in rough terrain while being able to complete manipulation tasks. One ideal application for these robots is item disposal, as no matter the location or hazardous nature of the item, they are equipped with the tools to complete this task and consequently removing any risk present to humans; in the case of radioactive material disposal, a legged manipulator would be able to complete this task without exposing humans to radiation and additionally only having operational time limited by the onboard battery, not radiation exposure.

Controlling these robots is no simple task. As these systems typically feature a high level of redundancy, a popular method of leveraging this redundancy, to utilise the whole robot to complete tasks, is to use a WBC [1]. However, this still leaves the issue of creating reference trajectories for the robot to follow to complete tasks. Artificial intelligence (AI) presents promising results for creating these references but this technology is not developed enough for critical tasks of a sensitive nature, such as when dealing with explosives or hazardous substances. Therefore, teleoperation with a human-in-the-loop is currently the optimal method of trajectory generation for controlling robots while completing these types of tasks.

Current research shows that combining teleoperation with a WBC creates an effective and efficient framework. However, these frameworks only offer a shallow level of control to the teleoperator, usually only providing control of dedicated manipulator end-effectors. Xin et. al developed a framework tailored for quadruped robot manipulation and sensing, using a 7 degree of freedom (DoF) joystick to generate reference trajectories and a WBC to utilise redundancy to realise these trajectories [2]. Although this framework demonstrates dexterous control of the quadruped's feet frames, not only is the teleoperator limited to controlling just the feet of the robot, but also the complexity of this joystick suggests that significant training would be required to yield the same results presented. A motion capture suit is paired with joysticks in [3] for low and high level control respectively in humanoid robots. However, it can only be used where direct kinematic mapping is possible. With such frameworks not being compatible with more kinematically stable robots, such as the quadrupedal manipulator, it presents these frameworks as sub-optimal for tasks of high risk in hazardous environments.

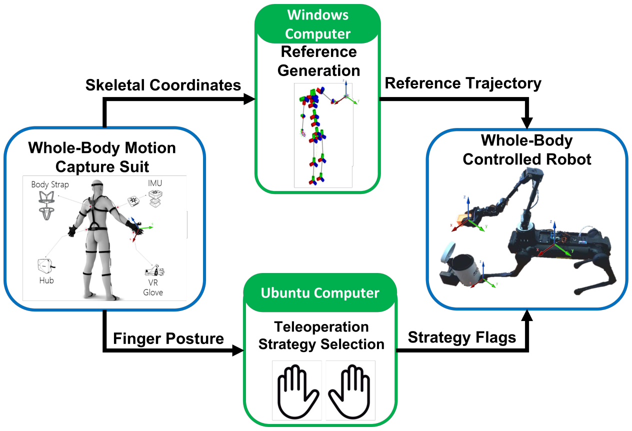

Fig. 1: An system overview of the teleoperation framework.

In this paper a teleoperation framework is developed, which features a range of teleoperation strategies to control the gripper, trunk and front left (FL) foot of a legged manipulator. A WBC is leveraged within the framework to generate efficient whole-body motions and control frames in select DoF. The proficiency of the framework is tested through completing an item disposal experiment that would otherwise be impossible without an additional manipulator.

II. SYSTEM OVERVIEW

The system is comprised of a ViperX 300 robotic arm mounted to an Aliengo quadruped robot. To generate the reference trajectories a Noitom Perception Neuron motion capture suit is used as it allows the user to move freely during operation and enables the use of the whole body for teleoperation. With the payload of the Aliengo being 13kg, the ViperX 300 has had its weight optimised using carbon fibre rods to improve performance [4]. The motion capture suit and robot are connected together through communication between

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Fig. 2: Snapshots of the teleoperator controlling the robot during the experiment.

a Windows computer (running the teleoperation algorithm) and an Ubuntu computer (running the WBC) through a 5GHz Wi-Fi router. This system is shown in Fig. 1.

III. WHOLE-BODY CONTROLLER

The WBC is formulated as a QP problem featuring a range of tasks and constraints to optimise for joint velocities $\dot{\boldsymbol{r}}$ [5],

$$\begin{aligned} \min_{\dot{\boldsymbol{r}}} \quad & \frac{1}{2}\dot{\boldsymbol{r}}^T \boldsymbol{A}^T \boldsymbol{A}\dot{\boldsymbol{r}} - \boldsymbol{b}^T \boldsymbol{A}\dot{\boldsymbol{r}} && (1) \\ \text{s.t.} \quad & \boldsymbol{C}_{\text{lb}} \leq \boldsymbol{J}_{\text{CoM}}\dot{\boldsymbol{r}} \leq \boldsymbol{C}_{\text{ub}} \, , && (2) \\ & \boldsymbol{J}_{\text{halt}}\dot{\boldsymbol{r}} = 0 \, , && (3) \\ & \dot{\boldsymbol{r}}_{\text{lb}} \geq \dot{\boldsymbol{r}} \geq \dot{\boldsymbol{r}}_{\text{ub}} \, , && (4) \\ & \boldsymbol{r}_{\text{lb}} \geq \boldsymbol{r} \geq \boldsymbol{r}_{\text{ub}} \, , && (5) \end{aligned}$$

where Cartesian tasks are stacked into $\boldsymbol{A}$ and $\boldsymbol{b}$. A stability constraint (2) keeps the CoM in the support polygon using $\boldsymbol{C}_{\text{lb}}$ and $\boldsymbol{C}_{\text{ub}}$ to describe the polygon bounds and $\boldsymbol{J}_{\text{CoM}}$ is the Jacobian of the CoM. A halt constraint sets zero velocity in select DoF of a frame is defined using its Jacobian, $\boldsymbol{J}_{\text{halt}}$, (3). To respect the real robots joint limits, $\dot{\boldsymbol{r}}_{\text{lb}}$, $\dot{\boldsymbol{r}}_{\text{ub}}$, $\boldsymbol{r}_{\text{lb}}$ and $\boldsymbol{r}_{\text{lb}}$ define the joint's lower and upper position and velocity limits.

IV. TELEOPERATION STRATEGIES

To fully utilise the reference trajectory generated by the skeletal data of the motion capture suite, shown in Fig. 1, a set of teleoperation strategies (TS) have been devised to provide the teloperator with a wide range of functionalities, enabling the teloperator to gain control of the gripper, trunk and FL foot. Furthermore, additional functionalities are built into the framework, including a homing function. In select modes the gripper is halted in either position, orientation or both to provide fine control and stability of the gripper if it is holding an item. These strategies are detailed in Table I.

V. EXPERIMENT

The objective of the experiment was to pick up an item (in this case a small box) off a surface above the robot, open the bin by pushing the peddle on the bin, reposition the trunk to 'look' into the bin (simulating when the teleoperator only has vision from the front robot cameras), drop the item into the bin and then release the peddle. To pick up the item, initially TS1a was used to get the gripper into a rough position close to the item and an orientation that aligns to it. Then TS1b is used lock the gripper in orientation for finer control when positioning it at the box, ready to pick it up using TS2a. Next the robot is brought to the home position, using TS5, for quick repositioning of the gripper. TS4 is then used to push the peddle of the bin with the FL foot. With the bin open, TS3 is used to orientate the trunk to pitch downward to 'look' into the bin. Using TS1b and TS2b, the gripper is positioned over the bin and the item is dropped in. Finally TS4 is used to raise the FL foot off the peddle to release it. Throughout the experiment, the whole body of the robot was observed to aid the frame being control in realising its task, such as the trunk adjusting its position and orientation as the gripper was reaching for the item. Snapshots of this experiment are presented in Fig. 2. A video of the experiment can be found at https://youtu.be/g6kn-nVD-_8.

TABLE I: Teleoperation Strategies: in the 'Left Hand' and 'Right Hand' columns 0 depicts a digit is open and 1 is closed.

Name	Feature Controlled	Gripper Halting	Left Hand	Right Hand
TS0	No Command	None	0,0,0,0,0	0,0,0,0,0
TS1a	Gripper	None	0,0,0,0,0	1,1,1,1,1
TS1b		Ori	0,0,0,0,0	0,0,1,1,1
TS2a	Close Gripper	Pos & Ori	1,0,1,1,0	0,0,0,0,0
TS2b	Open Gripper	Pos & Ori	1,0,1,1,1	0,0,0,0,0
TS3	Trunk	Pos	1,1,1,1,1	0,1,1,1,1
TS4	FL foot	Pos & Ori	0,0,1,1,1	0,0,1,1,1
TS5	Homing	None	1,1,1,1,1	1,1,1,1,1

VI. CONCLUSION

In this work a teleoperation framework has been developed to enable the teleoperator to utilise multiple frames of the robot to complete real world tasks through exploiting the set of teleoperation strategies implemented within the framework. The strengths of this framework have been demonstrated in an item disposal demonstration, where the gripper and FL foot frames are used as manipulators to complete tasks not normally possible with the control of only one manipulator. In future work, the teleoperation strategies will be further developed to introduce control of the rest of the feet frames and include static gait functionality.

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