A Simple Vehicle for the Transportation of a Humanoid Nao Robot

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Abstract

Locomotion and autonomy in humanoid robots is of utmost importance in integrating them into social and community service type roles. However, the limited range and speed of these robots severely limits their ability to be deployed in situations where fast response is necessary. While the ability for a humanoid to drive a vehicle would aide in increasing their overall mobility, the ability to mount and dismount a vehicle designed for human occupants is a non-trivial problem. To address this issue, this paper presents an innovative approach to enabling a humanoid robot to mount and dismount a vehicle by proposing a simple mounting bracket involving no moving parts. In conjunction with a purpose built robotic vehicle, the mounting bracket successfully allowed a humanoid Nao robot to mount, dismount and drive the vehicle.

Figure 1: A Nao robot mounted on the robotic vehicle. The mounting bracket supports the weight of the torso while the foot-rests prevent the feet of the Nao from dragging on the floor while the Naos leg motors are disabled.

1 Introduction

Humanoid robots, unlike conventional wheeled robots, are particularly suited to moving within human-centric environments. Obstacles such as doors and stairs that would present insurmountable barriers to a wheeled robot, can be easily overcome by a humanoid [Gini *et al.*, 2009]. For this reason, humanoids are particularly suited to domestic and service based roles, such as dealing with the elderly or people with disabilities [Okita *et al.*, 2009].

Additionally, humanoid robots, largely due to their ability to navigate human-centric environments, are particularly suited to the role of urban emergency and disaster response [Guizzo, 2014]. However, while these humanoids are adept at moving in such environments, their ability to mobilise to sites where they are needed is currently limited. Bipedal motion, which makes such robots suitable to human-centric environments, also provides a physical limitation on the speed and range of the robot [Denny, 2008]. This speed limit presents an issue in situations in which the robot is required to travel wide distances to arrive at where it will be needed most.

In order to address the issue of range and speed, humanoid robots therefore require access to a more efficient means of transportation. The ability to drive a vehicle, such as a car, would allow a humanoid, in the event of an emergency situation, to quickly deliver itself to where it is needed most.

Additionally, while humanoid robots are able to traverse environments not accessible to wheeled robots, wheeled robots provide greater energy efficiency when moving on flat terrain [Siegwart *et al.*, 2011]. By providing access to a vehicle, the life of a robots battery can therefore also be increased, allowing it to operate longer when it is needed.

However, the ability for a humanoid robot to mount and dismount a vehicle designed for human occupants is non-trivial. In an attempt to find a solution for this issue, [Guizzo, 2014] has listed the ability for a humanoid robot to mount, dismount and drive an unmodified human vehicle as one of the primary challenges of the DARPA Robotics Challenge. A question remains however, as to whether focusing on vehicles designed for human operation is the most effective answer to this problem, or whether more humanoid orientated methods of transportation can be found.

To address the issue of permitting a humanoid robot to mount and dismount a vehicle, this paper presents a simple mounting bracket without any moving parts, that when used in conjunction with a purpose built robot vehicle, allows a humanoid Nao to easily mount and dismount from the vehicle. The contributions of this paper are as follows:

- First, we describe a simple mounting bracket without any moving parts that is designed to allow a humanoid Nao robot to easily mount and dismount from a robotic vehicle while also locking the Nao firmly in place.
- Second, we describe a robotic vehicle that, when equipped with the mounting bracket, is capable of transporting a Nao robot.
- Lastly, we demonstrate the ability of the mounting bracket to firmly lock the Nao in place and prevent the Nao from falling out of the vehicle as a result of abrupt changes in motion.

The remainder of this paper is laid out as follows. Section 2 explores the background and related work. Section 3 describes the mounting bracket. Section 4 describes the robotic vehicle. Section 5 describes the experimental setup and Section 6 catalogues the results. Finally, we present a discussion in Section 7 and our conclusions in Section 8.

2 Background and Related Work

Bipedal locomotion is a key area of interest in the field of humanoid robotics research. In an effort to realise the most effective method of humanoid locomotion, researchers have investigated factors such as motion stability, energy efficiency as well as overall travel speed of these robots [Farizeh *et al.*, 2011].

The speed at which a humanoid can move presents a constraint with regard to its application in real world scenarios. While traditional methods of enabling bipedal locomotion have focused mainly on motion stability, energy efficiency and speed are also important factors in undertaking long distance travel. To address this issue, much work has been done in the area of human-like motion for humanoid robot, in order to improve both energy efficiency[Kulk and Welsh, 2008; Moro *et al.*, 2012] and speed [Yussof *et al.*, 2008].

However, while researchers strive to increase the overall speed and range of humanoid robots, the bipedal nature of humanoid robots imposes an upper limit on the maximum speed that can be achieve by these robots. According to [Denny, 2008], the maximum speed of a human is limited by factors such as height, mass, aerodynamics, anaerobic capacity as well as travel distance. While these factors were determined within the context of humans, they are also either direct factors, or analogues to factors affecting speeds for humanoid robots.

Therefore, in order to increase the speed at which humanoid robots are able to travel over distance, other means of locomotion must be investigated. For this reason, we have decided to investigate the use of motor vehicles as a method of transportation. However, while the ability for a humanoid robot to utilise a motor vehicle would vastly increase its ability to travel over large distances, we have been unable to find much work in this field.

While research on humanoid robots independently driving a vehicle might be scarce, a method for piloting a backhoe through tele-operation of a humanoid robot is presented in [Hasunuma *et al.*, 2003]. This research involved having the robot sit itself in the driver seat, and then through the use of tele-operation, manipulate necessary levers to perform a series of actions. While the robot was able to seat itself correctly, issues such as balance and mechanical constraints were highlighted as impacting on the success of the seating operation. Further, the robot had to be positioned in front of the seat in order to seat itself correctly.

While the ability for a humanoid robot to sit itself in a vehicle intended for humans in non-trivial, robotic vehicles designed for the task of transporting humanoids provides a potentially elegant solution to this problem. iCart II, presented in [Kashiwazaki *et al.*, 2011], describes a multi-robot platform, that through the use of a specially designed lifter module, allows multiple robots to collaboratively lift and transport cars. To avoid damage to the body of the car, this lifting module is purpose designed to slide under and lift a wheel of the car.

3 The Mounting Bracket

This section describes a novel mounting bracket containing no moving parts such as grippers. When attached to a robotic vehicle, the mounting bracket allows a humanoid Nao robot to easily mount and dismount the vehicle. Further, the mounting bracket is designed to lock the Nao in place to prevent it from falling from the vehicle as a result of abrupt changes in motion.

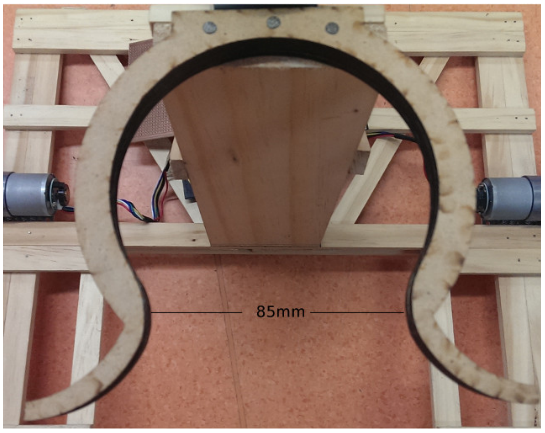

Figure 2: The Ω shaped mounting bracket is designed to easily slot around the waist of the Nao robot.

In our attempt to design a mounting bracket that could be easily utilised by a humanoid Nao robot, a strong emphasis was placed on ensuring that the mounting bracket did not include any moving parts. This was to ensure that the final design would be easily reproducible while also being low cost. To achieve this goal the physical shape of the Nao robot was exploited.

Initial designs ideas involved the use of bars that would slide under the arms of the Nao robot. By sloping the bars in a downward angle toward the back of the vehicle, the Nao would slide back against a backplate when lifting its legs off the ground, locking itself in place. However, these designs were quickly discarded as locking the robot in place involved applying stress to the shoulder joints of the Nao.

To address the issues presented in early designs, a new bracket was developed that takes advantage of the conic shape of the Nao robot's torso. Keeping with the theme of a simple design, an Ω shaped bracket with no moving parts was designed that could easily slide around the waist of the Nao (see Figure 2). The 85mm opening of the bracket is wide enough to only permit the torso of the Nao to enter or exit the bracket at a height of between 280mm and 290mm (see Figure 3). In the event that the vehicle and Nao are not perfectly aligned, the two curved sections at the front are designed to assist in guiding the Nao into place. Once in place the Nao attempts to sit, allowing the bracket to slide higher on the waist, physically locking the Nao in place (see Figure 1).

While the mounting bracket is capable of supporting the entire weight of the Nao, foot-rests were added on each side of the bracket in order to distribute the weight of the Nao more evenly. These foot-rests, as well as reducing the load on the bracket, allow the Nao to turn off its motors when driving the vehicle while preventing its feet from dragging on the floor. Further, by turning off its motors, the Nao is able to conserve energy, thereby increasing its overall operational time.

4 The Vehicle

In order to demonstrate the ability of the mounting bracket to enable a humanoid Nao robot to easily mount and dismount from a vehicle, a simple robotic vehicle was developed (see Figure 4). This vehicle was equipped with the mounting bracket and designed to incorporate the two foot-rests.

A primary consideration in the development of the robotic vehicle was that access to the mounting bracket and foot-rests should not require the Nao to climb on to the vehicle in any manner. For this reason, the front of the vehicle was opened to allow easy access to the mounting bracket. Additionally, the frame of the vehicle was designed to be strong enough to withstand the weight of the Nao robot(4.3kg) under situations such as mounting, dismounting and while the vehicle is in motion.

In order to ensure that the vehicle had sufficient torque to overcome the weight of the Nao, two Pololu 37D mm

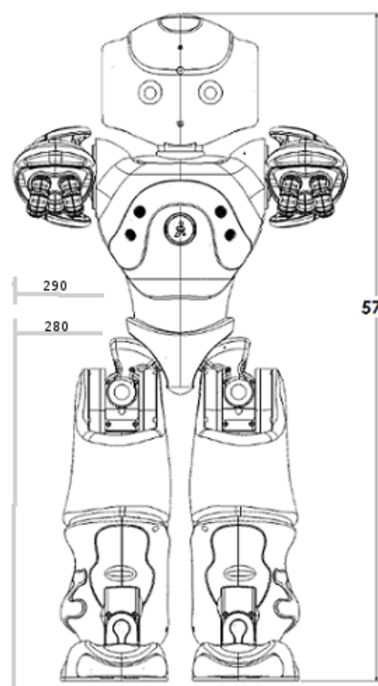

Figure 3: The 85mm opening of the mounting bracket is able to slide around the waist of the Nao at a height of 280mm to 290mm. Once inside, a Nao can lock itself in place by lowering its torso into the bracket.[1]

[1]Image from Aldebaran Robotics: https://community.aldebaran.com/doc/1-14/family/robots/links_robot_v33.html#robot-links-v33 last visited: 29/08/2014

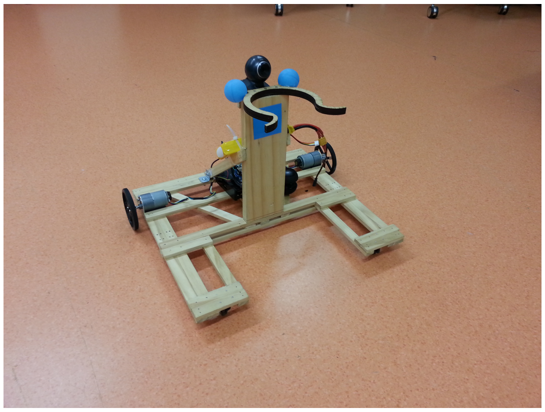

Figure 4: The robotic vehicle equipped with the mounting bracket. The foot-rests are clearly visible on either side of the mounting bracket.

gear motors were used. Additional electrical components of the vehicle included a Raspberry Pi microcomputer and a wireless dongle, to facilitate communication between the Nao and the vehicle, as well as a L298N motor controller to interface between the Raspberry Pi and the motors.

Communication between the Nao and vehicle was facilitated by a wireless local area network. Using the inbuilt wireless capabilities of the Nao as well as the wireless dongle attached to the Raspberry Pi, the Nao is able to transmit data directly to the software controlling the motors of the vehicle. This includes data such as continuous linear and angular velocities, as well as instructions for the vehicle to move a relative distance.

5 Experimental Setup

This section describes the experiments undertaken in order to validate the design of the proposed mounting bracket. These experiments involve a humanoid Nao robot and the robotic vehicle performing a set of tasks, which are described in the following subsections.

5.1 Mounting/Dismounting

This task is intended to demonstrate the ability of the novel mounting bracket in allowing a humanoid Nao robot to easily mount and dismount from the robotic vehicle. In order to complete this task successfully, the Nao and vehicle must successfully complete 4 distinct stages. Each stage must be completed successfully for the Nao and vehicle to progress on to the next stage. In the event that a stage is not completed successfully, the further stages are aborted and the task is considered to have ended in failure.

A description of the individual stages that must be completed are as follows (see also Figures 5 and 6).

Stage 1. Approach

Initially, the Nao is placed at a distance of 30 centimetres in front of the vehicle with its back facing toward the vehicle. At this stage, both the vehicle and Nao robot are in an idle state, with the Nao in a crouching pose waiting for the stage to begin.

On commencement of this stage, the Nao is required stand and transmit a command to the vehicle instructing it to drive forward. The vehicle will then drive forward until it has made contact with the Nao, causing the mounting bracket to slide around the waist of the Nao. The vehicle then instructs the Nao that it has arrived, and is ready for the Nao to mount.

Stage 2. Mounting

Once inside the mounting bracket, the Nao must lift its legs, lowering its torso into the mounting bracket in order to lock itself in place. At this stage, the Nao is securely locked in the bracket.

With the Nao being locked in place, the Nao will then lift its arms and swivel its legs outward, placing them onto the available foot-rests. This will allow the motors of the Nao to be turned off to avoid overheating while also preventing the feet of the Nao from dragging on the floor.

With the Nao firmly in the mounting bracket, with its feet planted on the foot-rests, the Nao is now ready to begin driving.

Stage 3. Dismounting

Having successfully mounted the vehicle, the Nao robot is then required to demonstrate its ability to dismount from the vehicle.

The process of dismounting from the vehicle requires that the Nao first lift its arms in front of its torso to prevent them catching on the mounting bracket. With its arms raised, the Nao must then perform the inverse of the mounting sequence in order to unlock itself from the mounting bracket.

At the conclusion of this stage, the Nao should be in a standing position within the mounting bracket. However, the Nao is not yet free to move around.

Stage 4. Separating

In order to conclude the task, and to allow the Nao to move about independently, the Nao must now instruct the vehicle to move away. This will cause the vehicle to reverse a short distance from the Nao, freeing it from the mounting bracket, before coming to a rest. The Nao will then revert to an idle state while re-assuming a crouched pose.

5.2 Driving the Vehicle

The purpose of this task is to demonstrate the ability of the mounting bracket to keep the Nao locked place while driving the vehicle. Additionally, this task also demonstrates the ability of the Nao robot to control the motion of the vehicle. For this task, it is assumed that the Nao is already mounted within the vehicle.

Initially the Nao will instruct the vehicle to move forward a pre-defined distance at a fixed velocity. Once the vehicle has travelled the required distance, it must then stop abruptly. The Nao will then instruct the vehicle to complete an in-place turn, before again stopping abruptly. The Nao must then be able to dismount correctly from the vehicle in order to complete the task.

If at any stage the Nao is ejected from the vehicle, either through applied motion or abrupt motion changes, the a failed attempt will be recorded.

6 Results

6.1 Mounting/Dismounting

This task was completed a total of 10 times. For 9 of the 10 attempts the vehicle and Nao were successfully able to complete each of the 4 stages. However, on one occasion, the vehicle and Nao were unable to complete stage 1. The following section highlights the important findings from each stage.

Stage 1. Approach

This stage was attempted a total of 10 times, of which 9 attempts were completed successfully. Figure 5 highlights the progression of this stage.

Initially the Nao robot is placed at a distance of 30 centimetres in front of the vehicle. The Nao robot, standing in front of the vehicle as seen in Figure 5(a), then

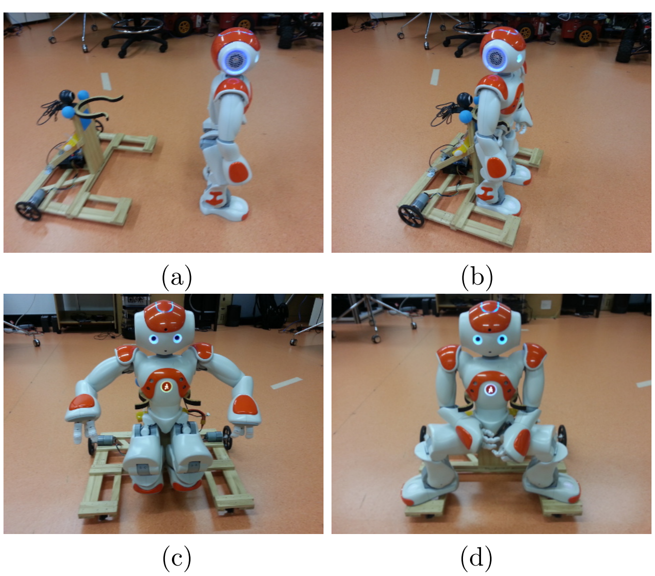

Figure 5: A Nao robot mounting the robotic vehicle with the aide of the mounting cradle.

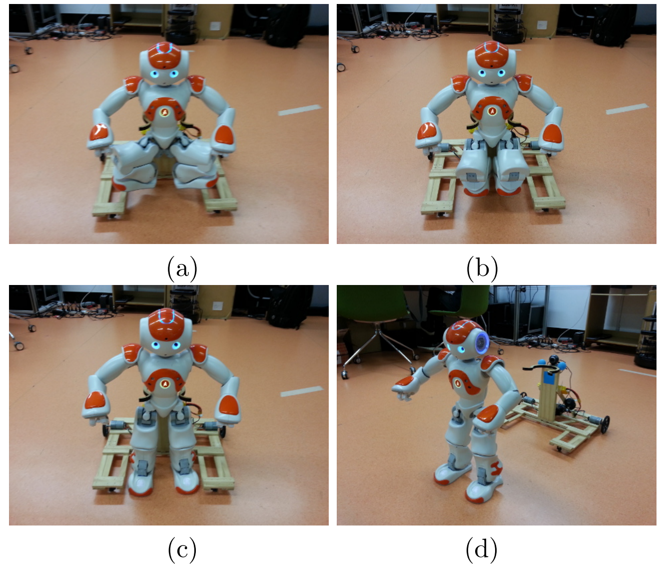

Figure 6: A Nao robot dismounting from the robotic vehicle.

instructs the vehicle to commence the mounting procedure. This causes the vehicle to drive forward, causing the Nao to slide in to the mounting bracket, as can be seen in Figure 5(b).

While 9 attempts were successful, 1 attempt ended in failure. This failure was caused by a slight deviation in the motion of the vehicle, causing the one of the foot-rests to collide with the leg of the Nao. This collision caused the vehicle to halt abruptly. While this attempt failed, it is notable that the fault was caused by the design of the vehicle, not the mounting bracket itself.

Stage 2. Mounting

This stage was attempted a total of 9 times, of which, 9 attempts were completed successfully. Figure 5 highlights the progression of this stage.

Standing with the mounting bracket, as seen in 5(b), the Nao initiates the mounting procedure by lifting its arms and legs in to the air, as seen in Figure 5(c). This causes the torso of the Nao to slide in to the mounting bracket, locking it firmly in place. The Nao then swivels its legs outward and places them on the foot-rests. The Nao is then disables its motors, and indicates to the vehicle that it has docked successfully.

Stage 3. Dismounting

This stage was attempted a total of 9 times, of which, 9 attempts were completed successfully. Figure 6 highlights the progression of this stage.

Resting in the mounting bracket, the Nao begins dismounting by first removing its legs from the foot-rests, as seen in Figure 6(a). Bringing its legs in front of its torso, seen in Figure 6(b), the Nao then places its feet on to the floor and moves into a standing pose, unlocking it from the mounting bracket, as seen in Figure 6(c).

Stage 4. Separating

This stage was attempted a total of 9 times, of which, 9 attempts were completed successfully. Figure 6 highlights the progression of this stage.

Standing within the mounting brace of the vehicle, as seen in Figure 6(c), the Nao instructs the vehicle to reverse away which can be seen in Figure 6(d). The Nao is now able to move about freely.

6.2 Driving the Vehicle

In order to ensure the reliability of the mounting bracket in securing the Nao in the vehicle, this task was completed a total of 5 times. For each of the 5 attempts, the Nao and vehicle were successfully able to perform the required actions with the Nao remaining firmly in the mounting bracket.

Further, on each attempt the Nao was successful in controlling the motion of the vehicle in order to accomplish the required set of motions. The Nao can be seen driving the vehicle forward, as well as in a circle in figures 7 and 8 respectively.

7 Discussion

While we initially intended to have the vehicle use visual servoing in order to approach the Nao, this proved to be unreliable. As such, we currently assume that the Nao will always be placed in front of the vehicle at a set distance, in order for the vehicle to approach correctly. However, this also relies on the Nao positioning itself correctly in front of the vehicle.

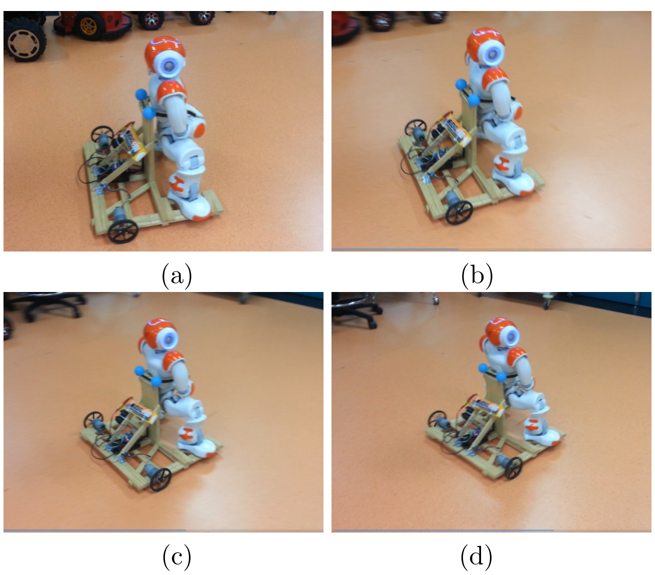

Figure 7: The Nao mounted on the vehicle and driving in a straight line. The mounting bracket locks the Nao in place preventing it from falling out while the vehicle is in motion, as well as if it halts abruptly.

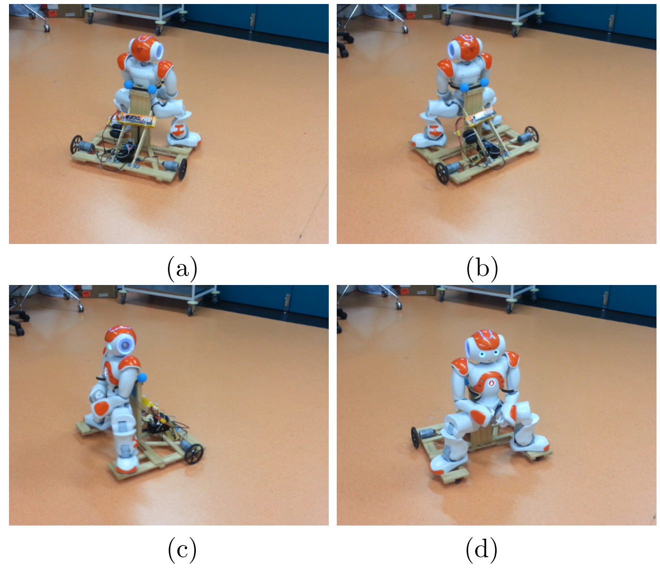

Figure 8: A Nao robot turning the robotic vehicle in place. The mounting bracket prevents the Nao from falling out the side of the vehicle as a result in abrupt changes in motion.

Further work was done to test whether the Nao could approach the vehicle from a distance, turn in place, and instruct the vehicle to commence the mounting procedure. However this proved problematic. While turning in place, the Nao was frequently unable to maintain the correct position in front of the vehicle as a result of instabilities in its motion. This would then typically lead to the foot-rest of the vehicle striking the Nao, halting the vehicle.

In order to address this issue, we therefore intend for future iterations of the vehicle to allow the Nao to face the vehicle while the vehicle is approaching. This will allow the Nao to provide guidance to the vehicle while it is approaching. The vehicle can then be designed to either pivot around the Nao while it is standing in the mounting bracket until the Nao is facing away from the vehicle, or to allow the Nao to mount while facing toward the vehicle.

While the vehicle demonstrated in this paper was capable of only carrying a single robot, we envision vehicles that could be equipped with multiple mounting brackets. This would allow such vehicles to serve as transport platforms for whole teams of humanoid robots, collecting them and depositing them swiftly en masse to where they are needed most.

Vehicles that are equipped specifically for the transportation of humanoid robots have a number of potential applications outside of urban disaster and emergency response. One such area where the technology could provide a potential benefit is the horticultural sector. By allowing humanoid robots to transport themselves to harvest-ready areas, these robots could potentially augment traditional fruit picking labour forces.

8 Conclusion

This paper presents a simple mounting bracket that without the use of moving parts is capable of allowing a humanoid Nao robot to mount, dismount and drive a simple robotic vehicle.

By taking advantage of the shape of the humanoid Nao robot, the use of moving parts in the mounting bracket was avoided. This allows the cost of the mounting bracket to remain low, while also allowing the bracket to be easily reproduced.

Additionally, by utilising the shape of the Nao robot's torso, the mounting bracket is capable of locking the Nao in place while the vehicle is in motion. This allows the vehicle to make abrupt course changes without dislodging the Nao from the bracket.

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