Design of a Wheeled Mobile Robotic Platform with Variable Footprint

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1. Introduction

The German Aerospace Center's Institute for Robotics and Mechatronics has recently developed an upper-body humanoid known as JUSTIN that incorporates two of its 7-DOF lightweight robotic arms [1]. For this system, a holonomic wheeled mobile platform with a variable footprint has been designed for operation in an indoor human environment.

2. JUSTIN system characteristics

Each arm weighs 14 kg, is 1.2 m long and is capable of lifting its own weight. The maximum joint speed is 180 deg/s. The torso adds 3-DOF and 19 kg for a total upper body mass of 48 kg. The dynamics of the large payload, reach and speed of the system pose challenges for the platform, which do not arise in other systems where the upper body momentum is negligible.

3. State of the Art

There currently exist two extremes in terms of indoor robot mobility – on the one hand, much effort is being put into developing dynamically balanced walking robots; on the other, 'traditional' designs have a large, heavy wheeled platform that is statically stable. While the former could ultimately be as mobile as a human, there is still much to be done in reaching the necessary stability, power, and energy efficiency, and it will always be a complex solution. The latter on the other hand uses simple, energy efficient wheeled propulsion but is typically bulky, restricting the robot's workspace and mobility due to its volume and girth. One attempt to solve this dilemma is to use a variable wheelbase structure [2]. A third option used by the Segway RMP is to dynamically balance on two wheels; it runs into problems when doing heavy manipulation [3].

4. Requirements

Stability was deemed the number one priority followed closely by mobility. The system needs to stably support JUSTIN, its own weight, and the payload – up to 28 kg from ground level, 3 kg at full horizontal extension. Of medium priority were safety, a large workspace, and power. The potential for injury of itself or persons should be small. Of lesser importance were precision, speed and a long runtime. It should travel at a quick walking pace of 6 km/h, accelerate at 2 m/s^2, be able to accelerate up a slope of 5^o at 0.5 m/s^2, and traverse 25 mm steps or sills. The overarching goal was to maintain and build on the strengths of JUSTIN.

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5. Evaluation Criteria

High stability and mobility in particular are often conflicting goals, since a small more mobile platform lacks the inherent stability of a large bulky platform. A weighted point-based system with the main categories of stability (33%), mobility (30%), complexity (20%), energy and power (10%), and safety (7%) was used to compare different configurations ranging from single wheel dynamic balance over variable footprint configurations to four-wheel static balance in different size and drive types. Quantitative measures such as minimum width, tip-over force or power needed for acceleration as well as qualitative measures such as control system complexity were evaluated.

6. Variable Footprint System

The chosen design configuration is a statically stable platform with four driven and steered wheels that can be independently repositioned to change the footprint of the platform from 41 × 61 cm to 83 × 104 cm. The footprint is rectangular to provide two workspace options – over the narrow side for maximum reach (Fig. 1), or over the wide side for maximum area. In order to achieve similar stability without the variable footprint the platform would need to be about twice as heavy or be as large as the maximum area. Yet a heavier platform requires more powerful drives, reducing runtime, and poses a greater safety risk with its increased momentum. A larger platform has the already mentioned reduction in mobility. Using a dynamically balanced platform instead would result in more tool-tip error and increase the likelihood of a catastrophic failure due to its reliance on constant actuation and control for stability.

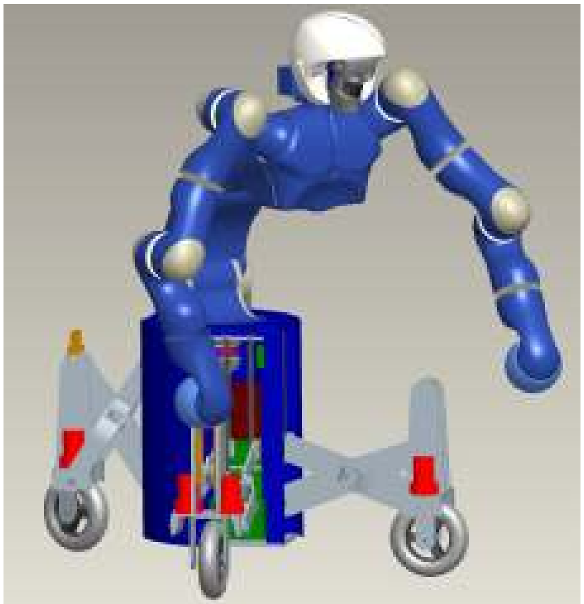

Fig. 1: CAD view of JUSTIN on mobile platform with legs extended from narrow side

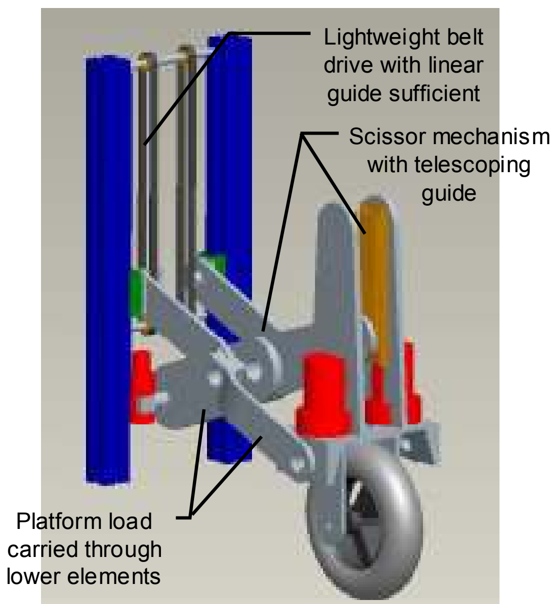

Fig. 2: Leg extension mechanism, fully extended

To change the footprint, a scissor mechanism is used (Fig. 2) which allows the leg to be horizontally extended ~40 cm without changing the height of the platform. Because the vertical load is carried through the lower members, the extension drive must only overcome friction in its bearings and small acceleration and disturbance loads, giving a power requirement of about 28 W. A non-linear relationship exists between the vertical drive and the horizontal extension travel such that the vertical drive speed required to maintain a constant horizontal extension speed increases rapidly as the scissor extension angle increases. Similarly, the horizontal bearing load also increases sharply. The angle is limited to 70°, at which point the vertical drive experiences a horizontal load of 1600N and must travel at 2.75 m/s to maintain 1 m/s horizontally.

7. Design Details

The platform stands 60 cm high and has a target weight of 50-60 kg, including 6 CPU units and 22 kg of batteries for ~2 hrs of runtime at an average power consumption of 1.2 kW, of which about 400 W is for base propulsion and steering, 500 W is for the upper body motion, and 130 W for the sensors and electronics. Tires are foam filled, 20 cm in diameter and are to be mounted with a simple spring-damper suspension.

Of the motion requirements, overcoming a sill is the most demanding, requiring a peak torque of 25 Nm per wheel, while a rated torque of 3.7Nm is sufficient for sustained acceleration. Considering motor winding, geartrain, and friction losses, a motor with a peak torque of around 370W is necessary.

By horizontally offsetting the wheel from the steering axis, holonomic motion is possible [4]. A worst case scenario considering wheel load under platform acceleration, a steering acceleration of 2 rev/sec^2 and velocity of 2 rev/sec results in a torque of 9 Nm per wheel for a output power requirement of about 60W.

8. Conclusion & Further Work

The mobile platform design manages to solve the conflicting goals of high mobility and stability with reasonably low complexity in a tailor-made package for the JUSTIN robot. The design will be refined and a finished product is expected to be presented in May 2008.

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