Supplementary materials

A Novel Gesture Recognition System for Intelligent Interaction with a Nursing-Care Assistant Robot

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**Stability check of the robot**

1. Stability checking theory analysis

According to the usage requirements of this robot, we check the stability of it under two different conditions: man-in-seat and no-man in seat. In addition, the check is based on the standard GB3811-2008.

According to the equal-force equilibrium equation and moment equilibrium equation, we have the stability equation of the static state as follows:

The stability equation of dynamic state is analyzed and defined as follows:

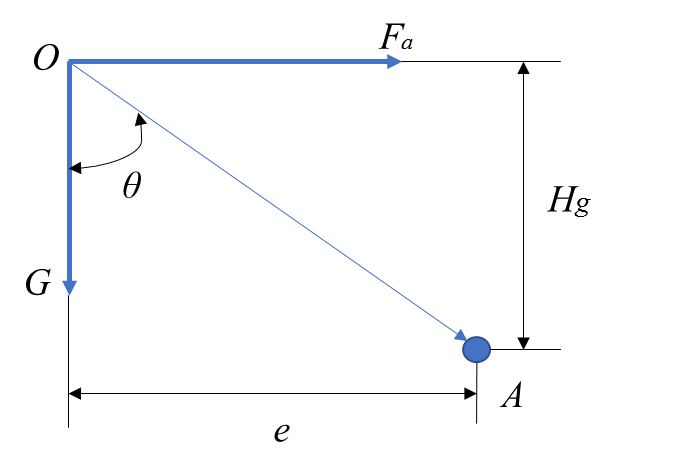
The parameters in Figure S1 are defined as follows:

*e* – Horizontal distance of the axis of gravity overturning;

*H*g – The vertical distance of the center of gravity from the ground;

*G* – Equivalent gravity of the center of gravity of an object;

*F* – The horizontal inertial force in the dynamic state of an object.



**Figure S1.** Schematic diagram of dynamic stability checking theory.

In order to ensure the stability under the dynamic state, should be satisfied, because , so we can get the threshold of the acceleration to avoid the unstability of the dynamic state. The robot’s unstability of the dynamic state in this study means its overturn during movement.

According to the theory analysis above, the stability check of the robot designed is classified by four main different conditions: robot static state or dynamic state; man-in-seat state; and no-man state. During the stability check, the longitudinal center line of the moving chassis is defined as the X-axis, and the horizontal transverse line parallel to the outer line of the cross beam in the rear of moving chassis is defined as the Y-axis. Then, origin point O is determined, and the vertical centerline of the frame over the origin point O is the Z-axis. According to the symmetry of the structure, it is clear that the moment of the whole body on the X-axis is completely balanced in the static state.

Before carrying out all kinds of stability check calculations, the mass calculation and the determination of the center of gravity of each part of the robot is carried out first:

Weight of YuMi installation part:

Weight of lifting-adjusting mechanism:

Weight of moving chassis:

Weight of seat:

Weight of robot:

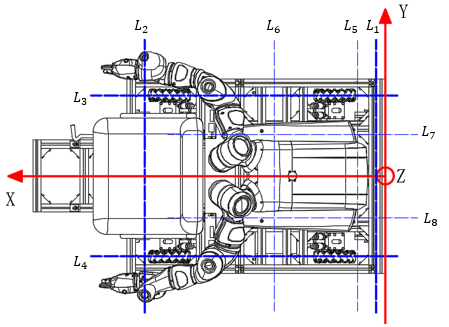
We assume the rider’s weight as *m*6 = 60kg.

2. Check of the robot’s stability in static state

In the static state, the stability of the man-in-seat state and the no-man state are checked separately.

2.1 Determination of overturning axis

In the X-axis direction, the overturning axes *L*1 and *L*2 are determined by the spin axes of the load-bearing wheels. In the Y-axis direction, the overturning axes *L*3 and *L*4 are determined by the width center of the driving wheels, as shown in Figure S2.



**Figure S2.** Schematic diagram of the overturning axis.

2.2 Calculation of all the parts’ centers of gravity

According to the weight of each part described above: *m*1 = 38.46 kg; *m*2 = 100 kg; *m*3 = 8.3 kg; *m*4 = 20kg; and *m*5 = 10 kg.

1) YuMi’s center of gravity:

*X*1 = 305 mm，*Z*1 = 910 mm; *X*1 = 305 mm，*Z*1= 1230 mm

2) Moving chassis’ center of gravity

*X*2 = 400 mm，*Z*2 = 134 mm；

3) Yumi installation part’s center of gravity

*X*3 = 255mm，*Z*3 = 589 mm; raising state: *X*3 = 255 mm，*Z*3 = 909 mm

4) Lifting adjusting mechanism’s center of gravity

*X*4 = 250 mm ，*Z*4 = 424 mm; raising state: *X*4 = 250 mm ，*Z*4 = 584 mm

5) Seat’s center of gravity

*X*5 = 805 mm ，*Z*5 = 388 mm

6) The user’s center of gravity in the sitting condition

*X*6 = 856 mm ，*Z*6 = 742 mm

2.3 Calculation of the robot’s center of gravity

1) Non-rising state:

No-man state:

According , *X* = 375.065 mm

According , *Z* = 377.378 mm

Man-in-seat sate:

According , *X* = 494.423 mm

According , *Z* = 467.87 mm

2) Non-rising state:

No-man state:

According , *X* = 375.065 mm

According , *Z* = 486.11 mm

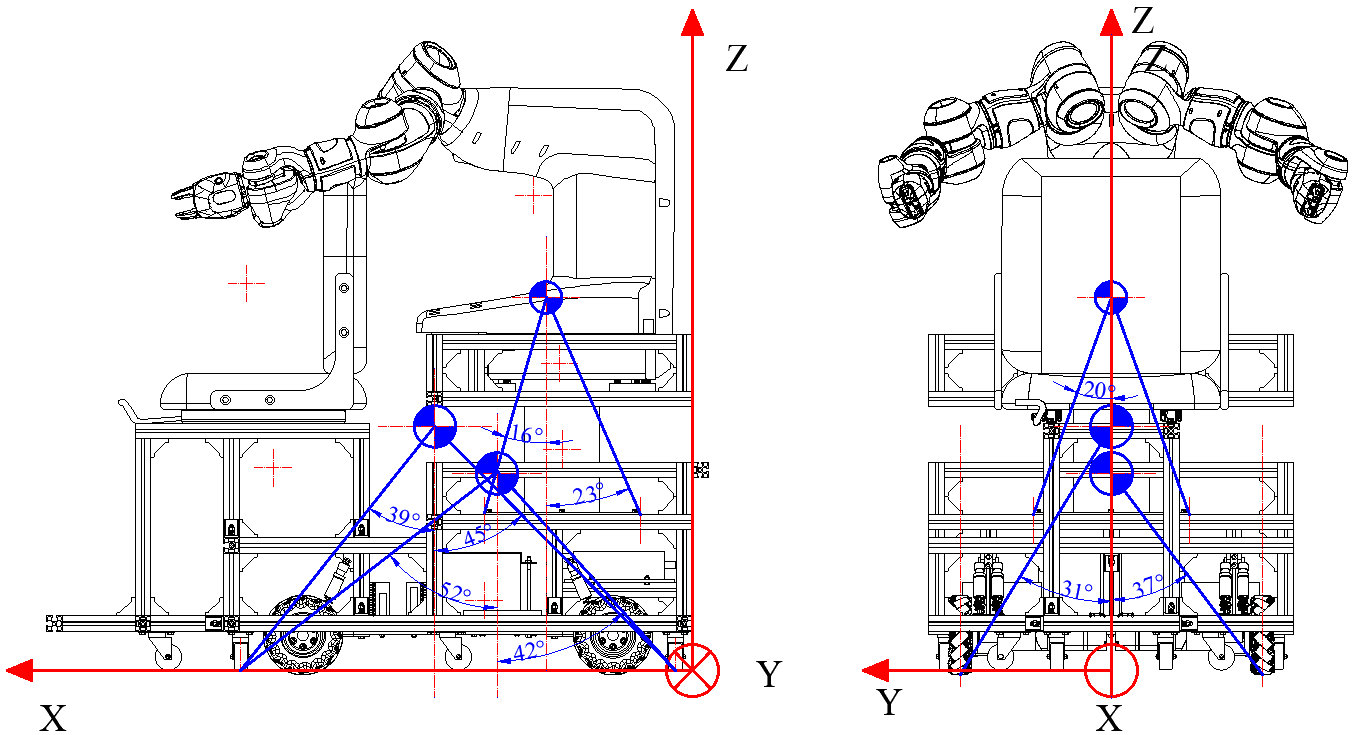
Man-in-seat sate:

According , *X* = 494.423 mm

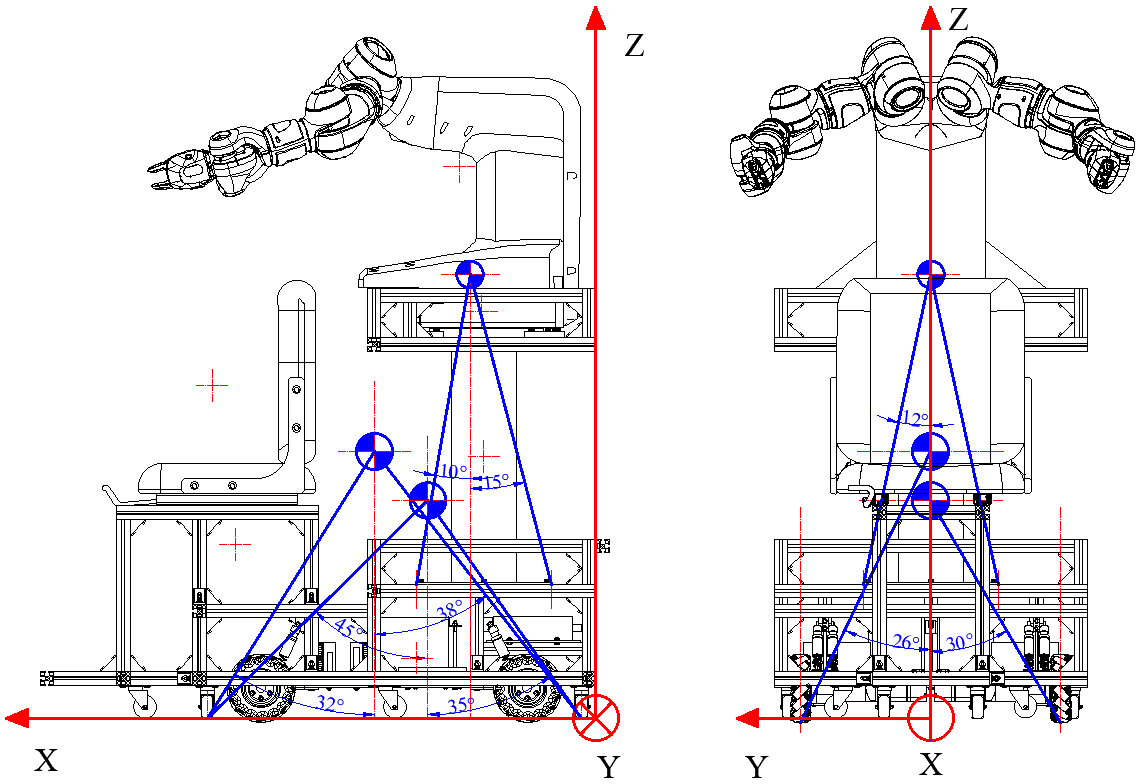
According , *Z* = 549.617 mm

2.4 Check of the stability

According to the calculation results of the robot’s center of gravity under different conditions, we checked the stability of the robot in the static state. The results are shown in Figure S3 and Figure S4. According to the national standards and theoretical analysis requirements, the center of gravity in the four working conditions falls within the overturning axis. Thus, the robot is stable in the static state.



**Figure S3.** Calculation of stability check for the lowest position (non-raising state) of lifting platform. (**a**) Side view of the robot for the display of X-coordinates and the analysis of longitudinal stabilities. (**b**) Main view of the robot for the display of Y-coordinates and the analysis of horizontal stabilities.



**Figure S4.** Calculation of stability check for the highest position (raising state) of the lifting platform. (**a**) Side view of the robot for the display of X-coordinates and the analysis of longitudinal stabilities. (**b**) Main view of the robot for the display of Y-coordinates and the analysis of horizontal stabilities.

3. Check of the robot’s stability in dynamic state

In the dynamic condition, should be satisfied according to the analysis of the theory above, and we can obtain the acceleration threshold according to , which can be used to ensure the dynamic stability of the robot.

3.1 Calculation of the acceleration threshold

According to the calculation of the centers of gravity all of the parts, we calculated the acceleration threshold as follows (the values of *g* used is 9.8m/s2, in other words, *g*=9.8m/s2):

1) Non-rising state:

1.1)Acceleration limit of the longitudinal stabilities：

No-man state:

*X* = 375.065 mm, *Z* = 377.378 mm, , threshold:

Man-in-seat sate:

*X* = 494.423 mm, *Z*=467.87 mm, , threshold:

1.2) Acceleration limit of the horizontal stabilities：

No-man state:

*Y* = 0 mm, *Z*=377.378 mm, , threshold:

Man-in-seat sate:

*Y* = 0 mm, *Z* = 467.87 mm, , threshold:

2) Rising state:

2.1) Acceleration limit of the longitudinal stabilities：

No-man state:

*X* = 375.065 mm, *Z* = 486.11 mm, , threshold:

Man-in-seat sate:

*X* = 494.423 mm, *Z* = 549.617 mm, , threshold:

2.2) Acceleration limit of the horizontal stabilities：

No-man state:

*Y* = 0 mm, *Z* = 486.11 mm, , threshold:

*Y* = 0 mm, *Z* = 549.617 mm, , threshold:

3.2 Check of the robot’s dynamic stability according to GB3811-2008

After the acceleration threshold is obtained, we checked the robot’s dynamic stability according to GB3811-2008. must be guaranteed in order to ensure the dynamic stability according to the standard.

1) Check of the dynamic longitudinal stabilities

According to the calculation above, is selected for the check in this condition. Here, according to GB3811-2008.

Due to , the check in this condition has been finished.

2) Check of the dynamic horizontal stabilities

According to the calculation above, is selected for the check in this condition. Here, according to GB3811-2008.

Due to , the check in this condition has been finished.