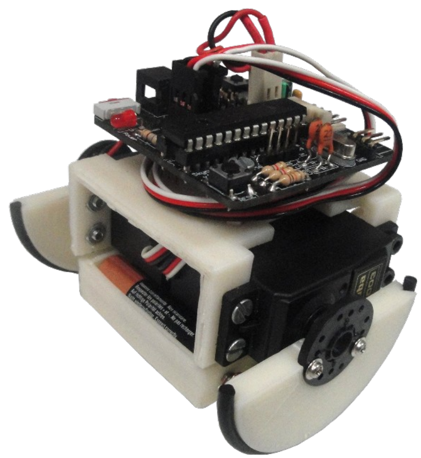
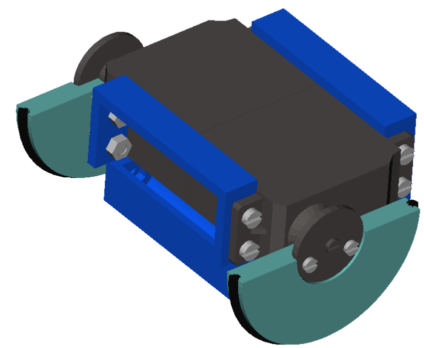
Motion Control of Differential Wheeled Robots with Joint Limit Constraints





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Outline

1. **Introduction**
2. Swing principle
3. Kinematics
4. Experiments
5. Conclusions and future work

Rolling principle

- Rolling behaviour is inherent to wheels
- Wheels are assumed to rotate indefinitely in any direction
- All kind of known wheels rely on it:

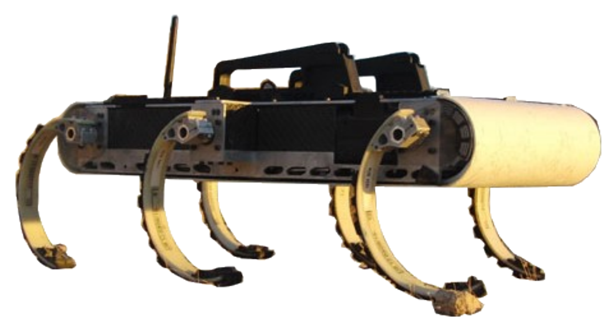
Standard wheel

Castor wheel

Swedish wheel

Whegs

Rotatory legs

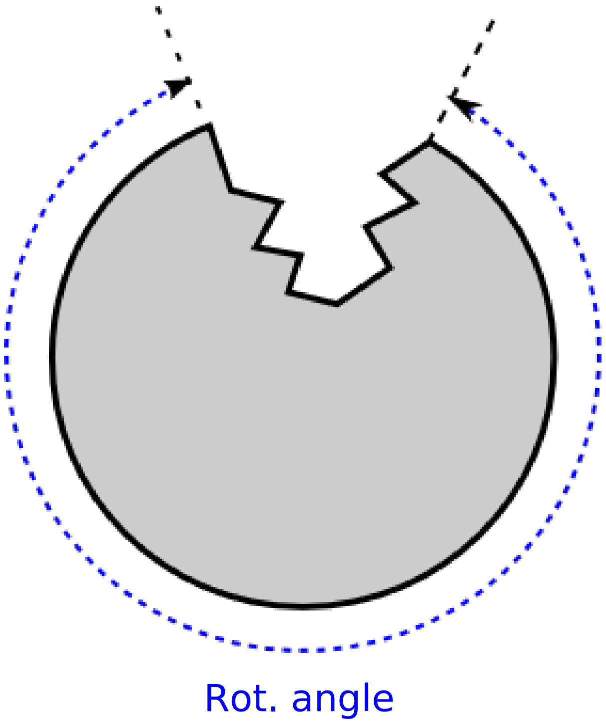


Limited wheels

Wheels that cannot turn freely due to constraints

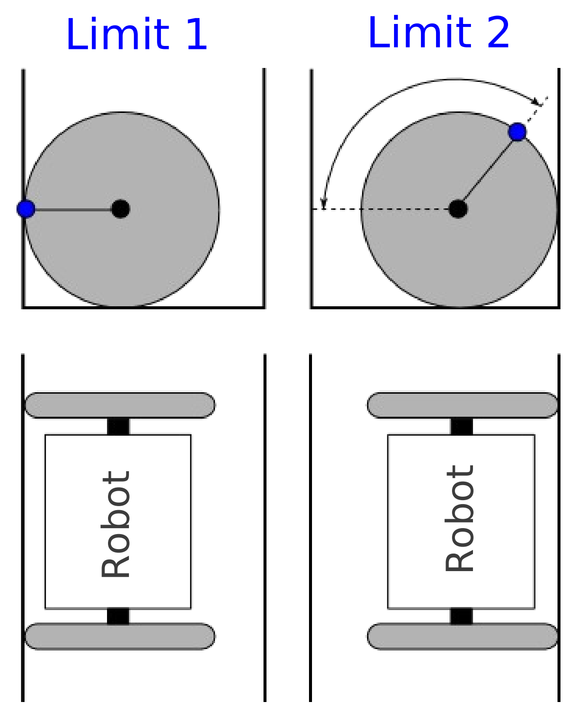
Limited by shape

Ex. Broken wheel



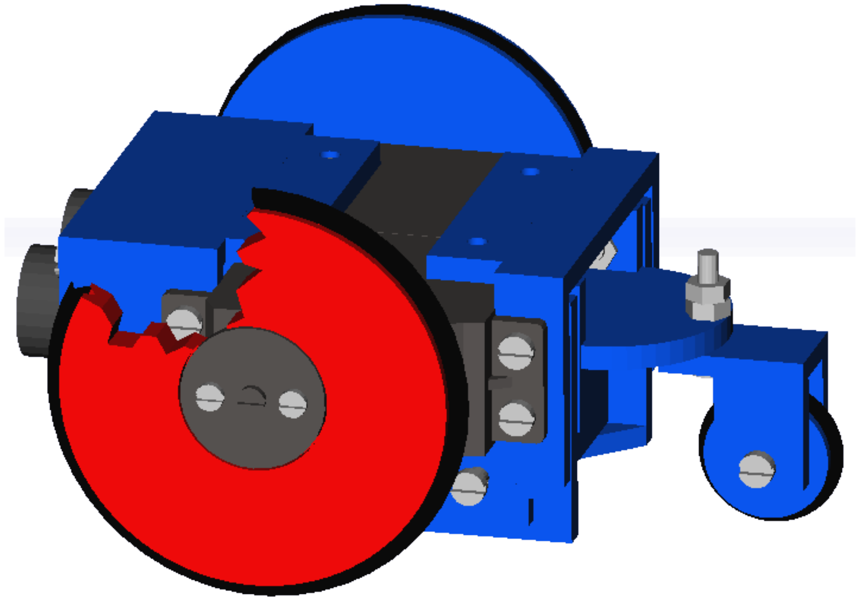
Limited by the environment

Ex. A Robot in a narrow path



Locomotion with limited wheels

The problem:



- Imagine a robot with a broken wheel...
- Is it possible to achieve locomotion with limited wheels?
- The rolling principle cannot be applied
- Another locomotion principle is necessary...

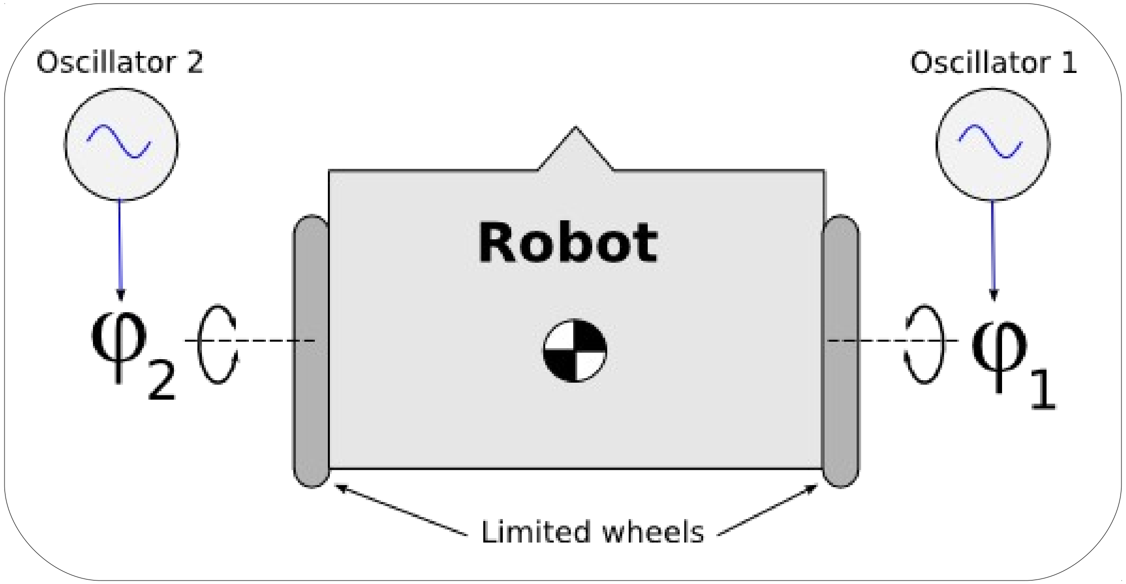
Applications:

- Improving the fault-tolerance of robots in critical missions
- Recovering the robot if wheels break
- Study and Develop new “locomotion gaits” with wheels

Our contribution: the swing principle

- **Swing principle**: Oscillating the wheels within the angle limits

- Differential robots with limited wheels can travel any distance in some directions if applying the swing principle



Oscillations:

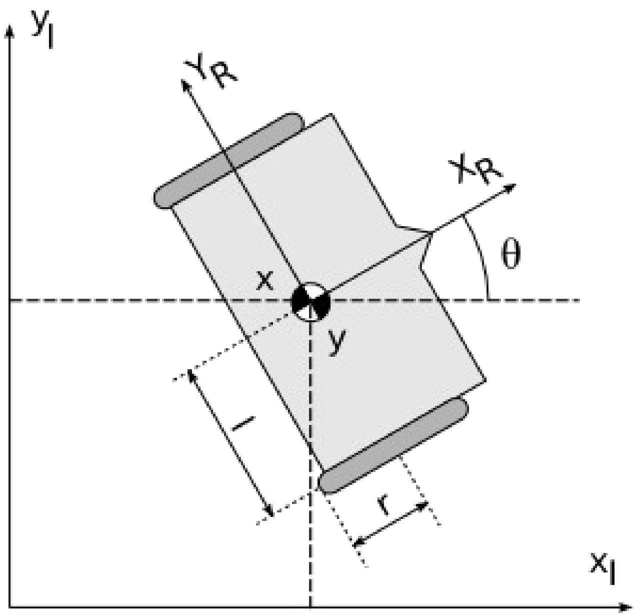
$$\varphi_1 = A\sin\left(\frac{2\pi}{T}t + \phi_0\right) + O$$

$$\varphi_2 = A\sin\left(\frac{2\pi}{T}t + \Delta\phi + \phi_0\right) - O$$

Parameters: Amplitude (A), Offset (O)

Period (T), Phase difference ($\Delta\phi$)

Kinematics



- {Yi, Xi}: Global frame
- {XR,YR}: Robot frame
- (x,y,θ): Robot position and orientation
- **r**: Wheel's radius
- **l**: Distance from the wheels to the com

- **Forward kinematics**:

$$\dot{x} = \frac{\pi r A}{T}(C(0) + C(\Delta\phi))\cos\theta$$

$$\dot{y} = \frac{\pi r A}{T}(C(0) + C(\Delta\phi))\sin\theta$$

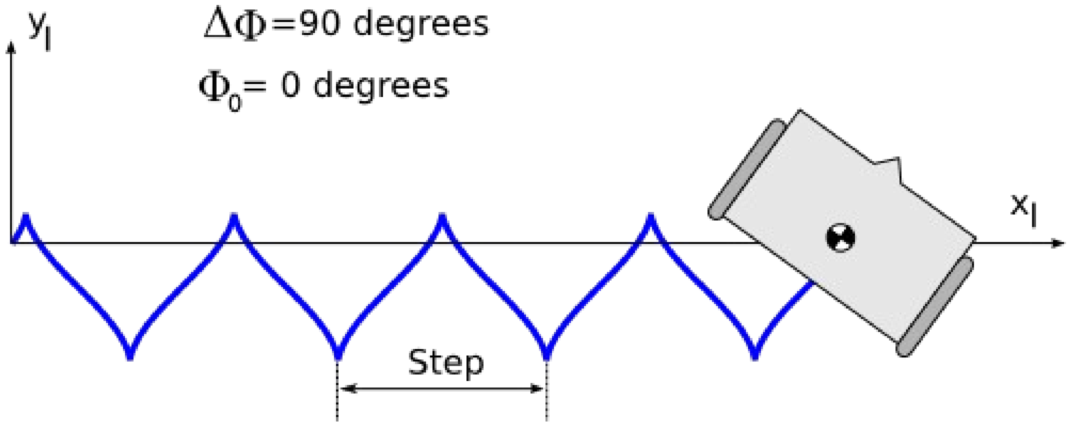
$$\theta = \frac{r}{2l}(A S(0) - A S(\Delta\phi) + 2O)$$

$$C(x) = \cos\left(\frac{2\pi n}{T} + \phi_0 + x\right)$$

$$S(x) = \sin\left(\frac{2\pi n}{T} + \phi_0 + x\right)$$

Locomotion gait and trajectory

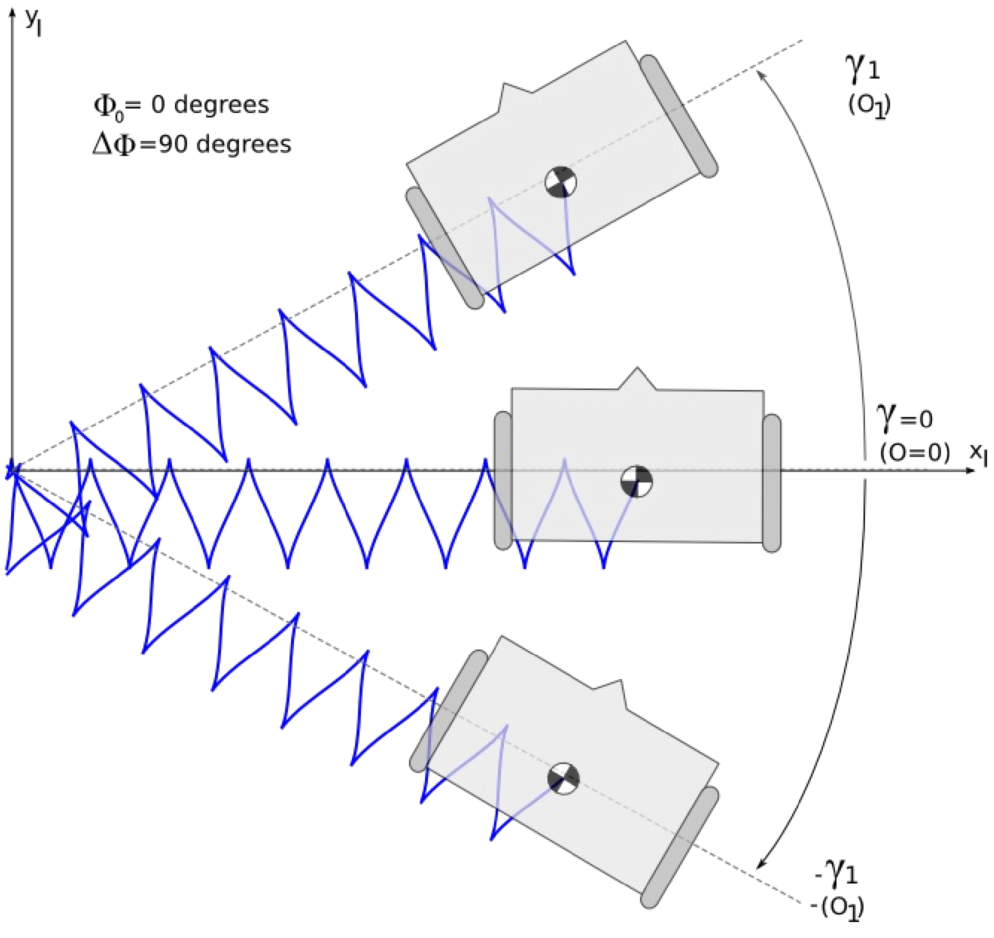
- The robot moves sideways
- Step: distance travelled per cycle



- When $\Delta\phi=90$ the step is maximum
- The step is proportional to the amplitude (A)
- The period determines the mean speed along the x axis

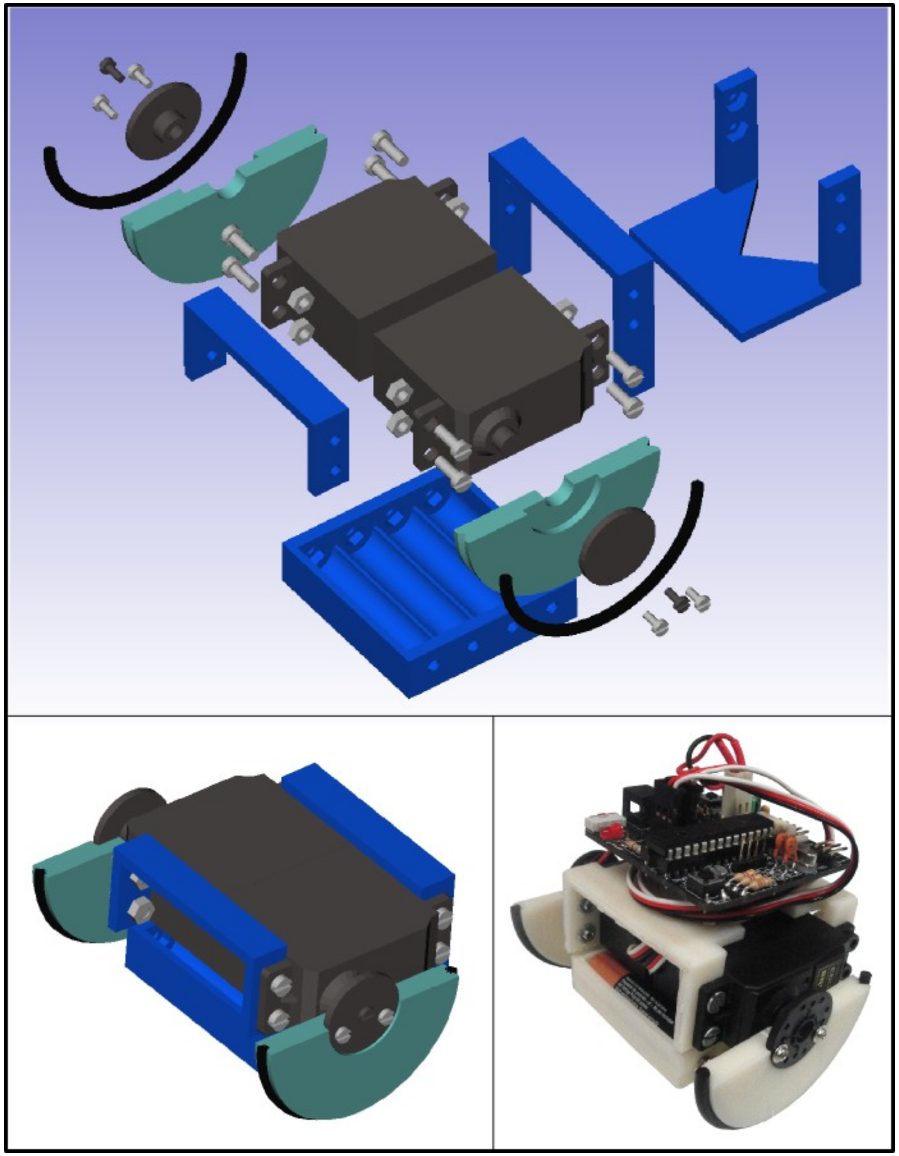
Trajectory orientation

- The robot can also move in different directions
- The trajectory orientation depends on the offset (O)



- **Limitations**:
- The robot **cannot** move in all the directions
- Increasing O implies decreasing the Amplitud (A)
- When A=0, there is no locomotion

Experiments (I)

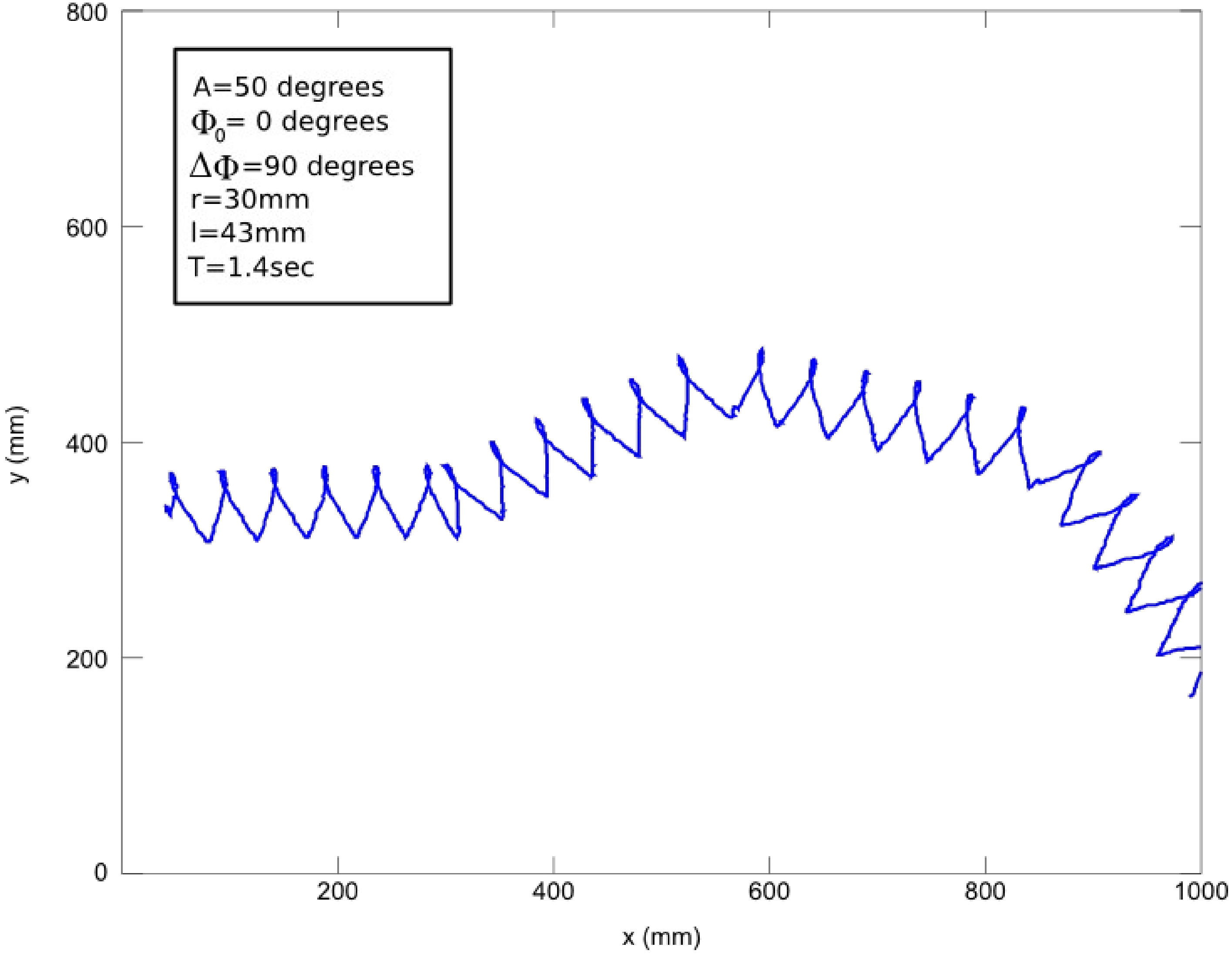


- A robot prototype with **limited wheels** has been designed and built
- Wheels limited by shape
- Servos with mechanical limits
- IR led on the top for tracking the trajectory

Experiments (II)

Video

- Real trajectory performed by the robot



Conclusions

- **Swing principle**: A new locomotion principle for robots with limited wheels has been proposed
- It is based on wheels' oscillatory movement
- Despite the limited wheels, the robots can travel any distance in some directions

Future work

- Test the swing principle with bio-inspired oscillators, such as CPGs (Central Pattern Generators)
- Application to tracked robots
- Application to climbing slopes
- Application to wheelchairs

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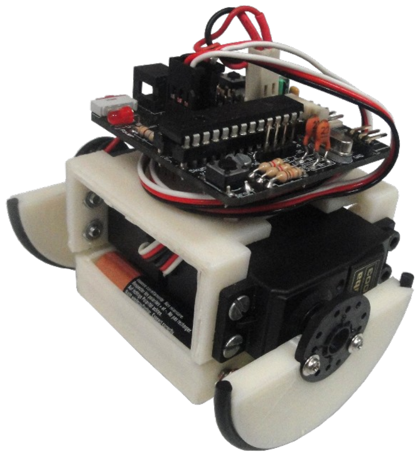

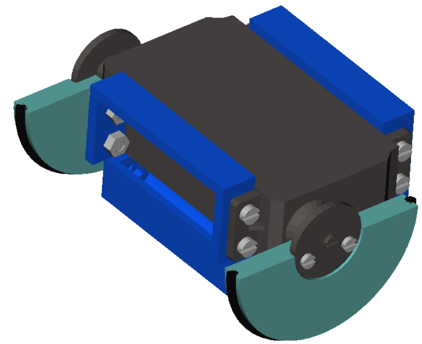

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