Unconventional Gait Exploration with Pleurobot. The Side-Winding Gait

Semester Project Presentation

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EPFL

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Remembering The Gait (I)

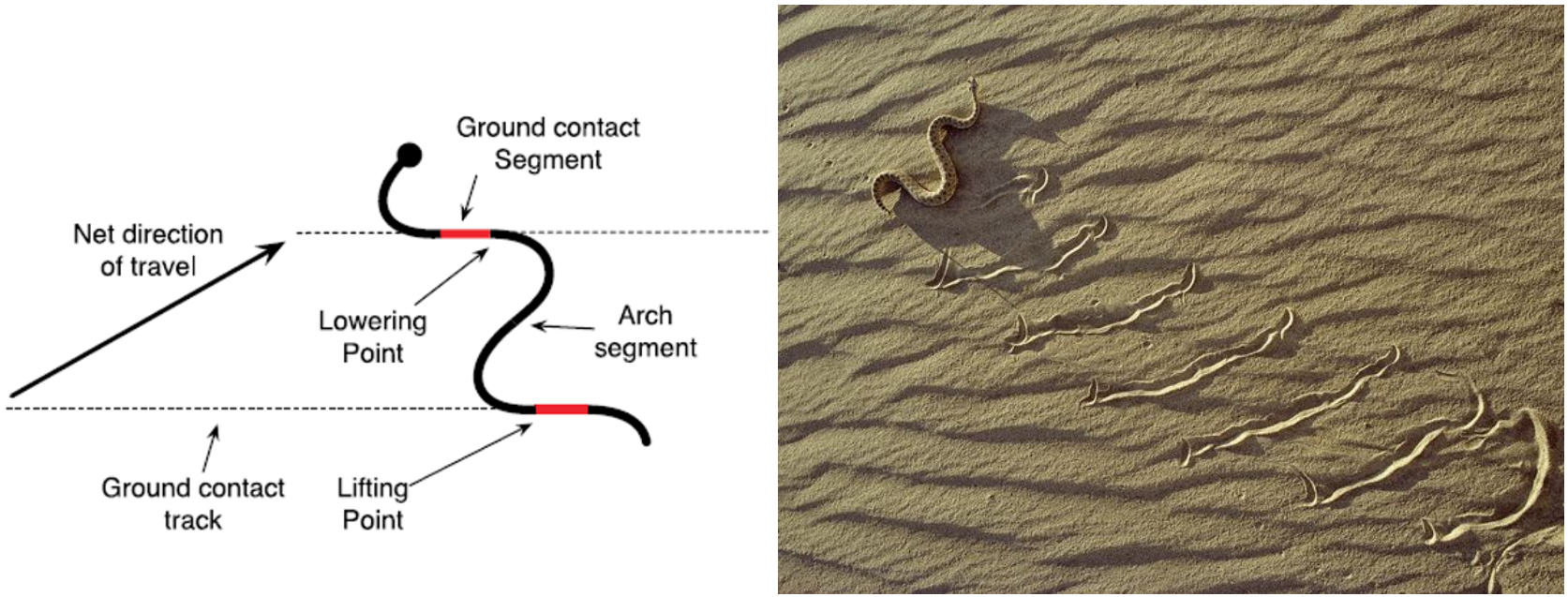

Figure 1: Ground Contact Tracks. Image source: Gong et al, 2012 and *http : //animals.nationalgeographic.com*

Remembering The Gait (II)

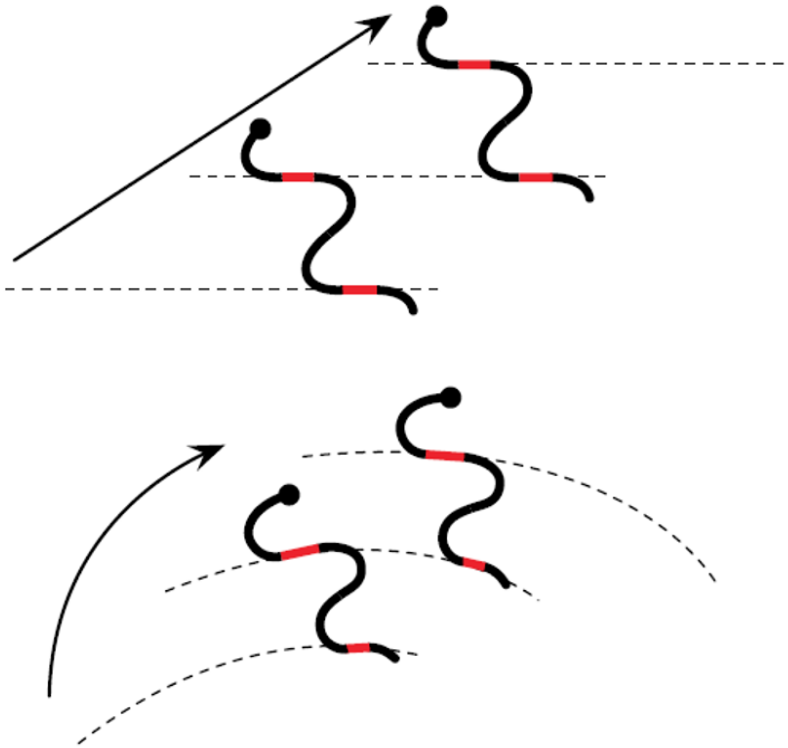

Figure 2: Conical side-winding. Images source: Gong et al, 2012

Remembering The Gait (III)

$$\Theta(n,t) = \begin{cases} A_o Sin(\frac{n}{\lambda} + \omega t), n = odd \\ A_e Sin(\frac{n}{\lambda} + \omega t + \delta), n = even \end{cases} \quad (1)$$

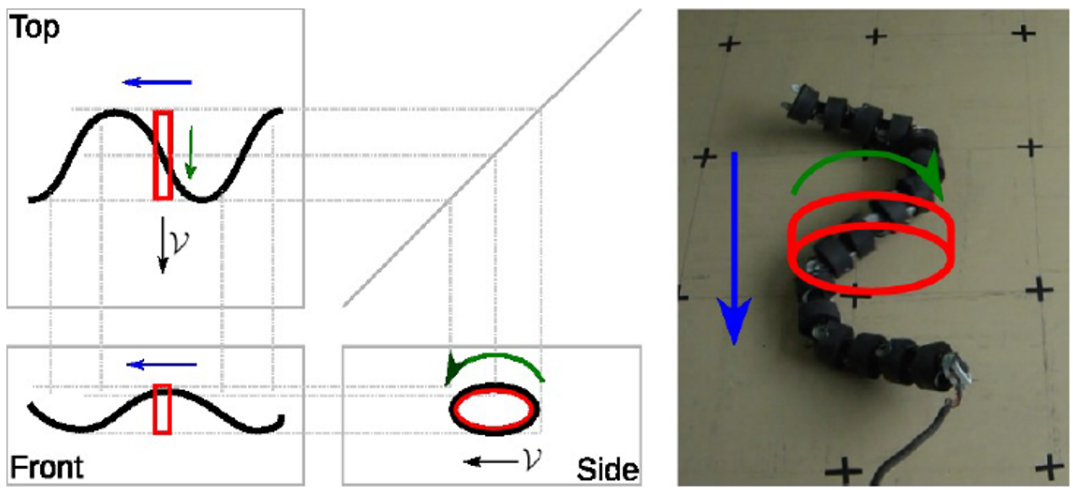

Figure 3: Top perspective-high amplitude wave , front perspective w.r.t the direction of dispalcement-low amplitude wave , and lateral perspective-ellypsoidal wheel . Image source: Melo, 2015.

Advantages (I)

Side-winding is desirable because (Burdick et al, 1993 and Hatton et al, 2010)

- Terrain-wise
  - Big footprint of the snake on the ground $\Rightarrow$ improved stability
  - Static, not sliding friction $\Rightarrow$ minimal frictional resistance from its environment
  - Useful on granular terrain where the ground is not generating enough reaction forces needed for other motions
  - Contact reaction forces are distributed over several GCS $\Rightarrow$ improved stability (Burdick et al, 1993)

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  - Only static friction $\Rightarrow$ not wasting energy on resistant forces
  - Low energy used for the vertical motion, which is very small

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  - Only static friction $\Rightarrow$ not wasting energy on resistant forces
  - Low energy used for the vertical motion, which is very small
- Performance-wise
  - Big speed
  - Reduced wear caused by friction

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From Snakes to Pleurobot

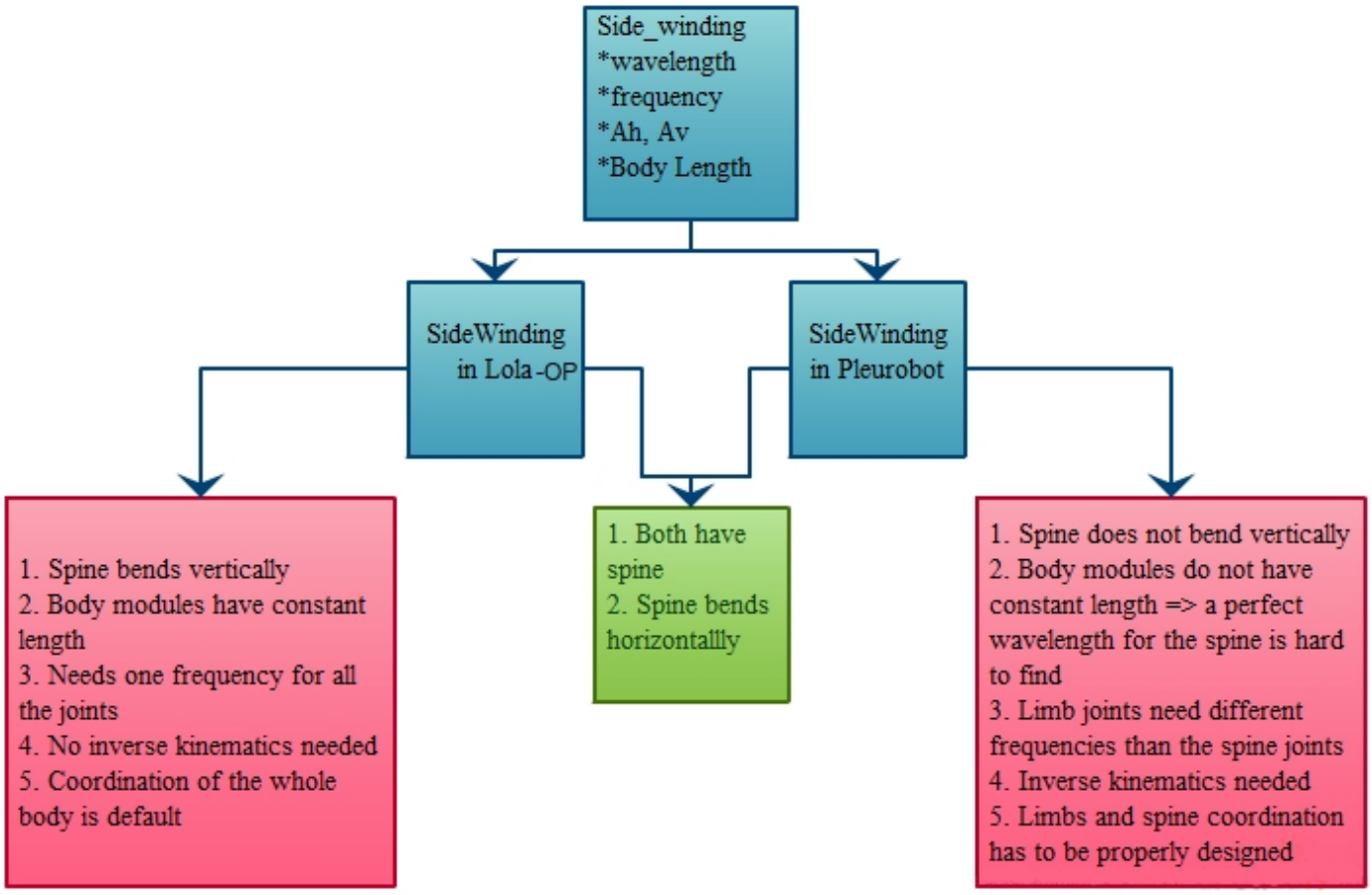


Figure 4: How can the wave-wave-roll motion be implemented in Pleurobot?

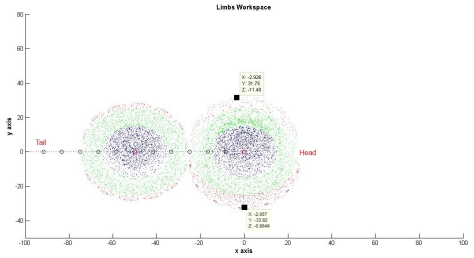
The Question

How can the 4 DOF limbs be exploited, to produce the vertical wave effect present in the snake's spine?

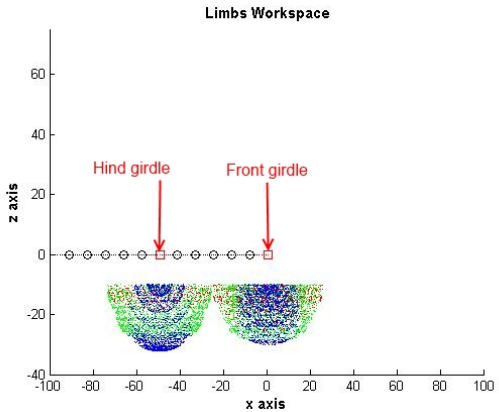
A First Step

The workspace

a) Top



b)Side



c)Front

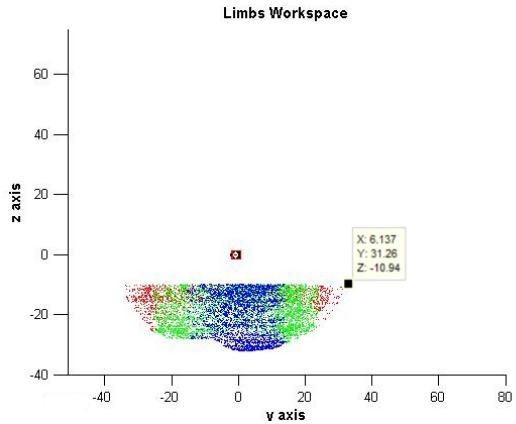


Figure 5: The Pleurobot's limbs workspace:a) Top view, b)Side and c)Front. In red the points with the distance w.r.t. the girdle greater than 25 cm, green the points with the distance w.r.t. the girdle between 15 and 25 cm, and in blue the points located at less of 15 cm on x and y w.r.t. the girdle.

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Approaches

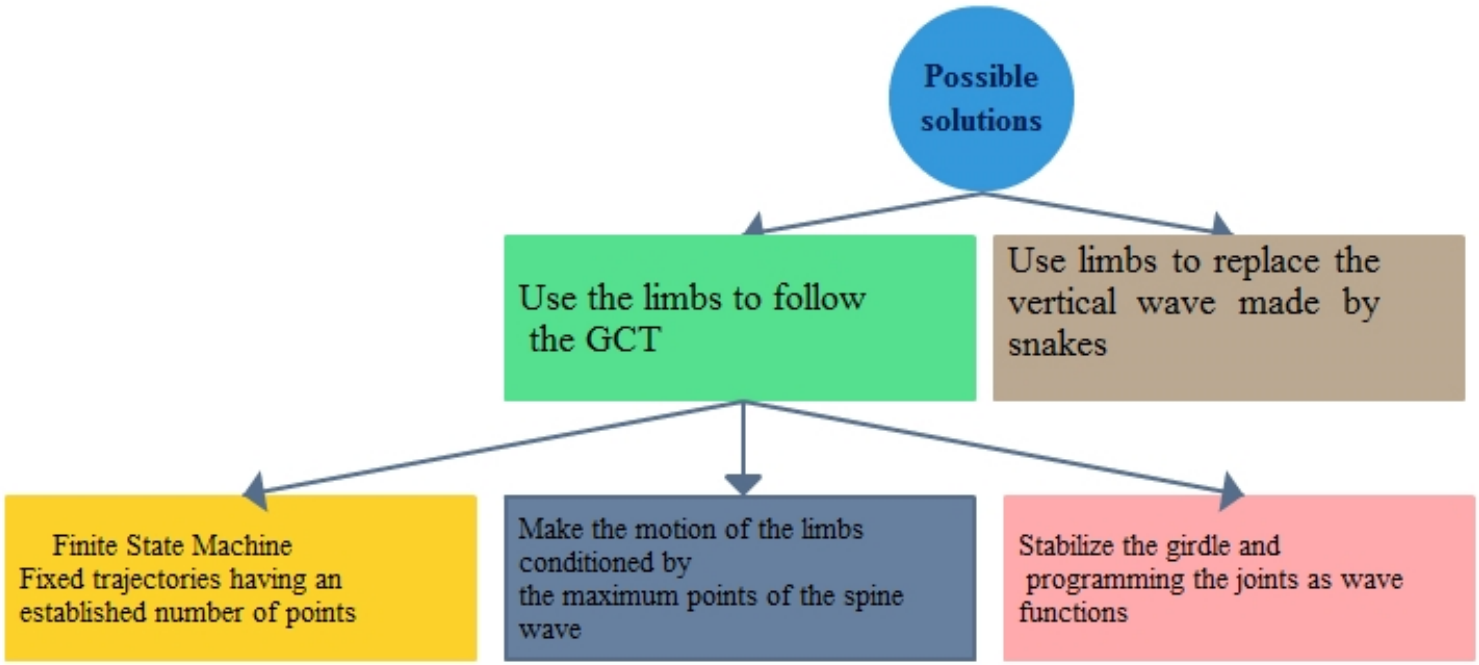


Figure 6: The charts shows different approaches proposed in order to implement the side-winding gait on Pleurobot

Metrics and Cases

Metrics:

- Speed of linear displacement on y = desired
- Speed of linear displacement on x = deviation from the desired trajectory
- Orientation of the Robot's Frame of Reference (Front-Hind girdle)
- Treadmill speed for the real Pleurobot's gaits

Cases:

1. Using all spine
2. Using half a spine (disabling the tail)
3. Not using spine at all

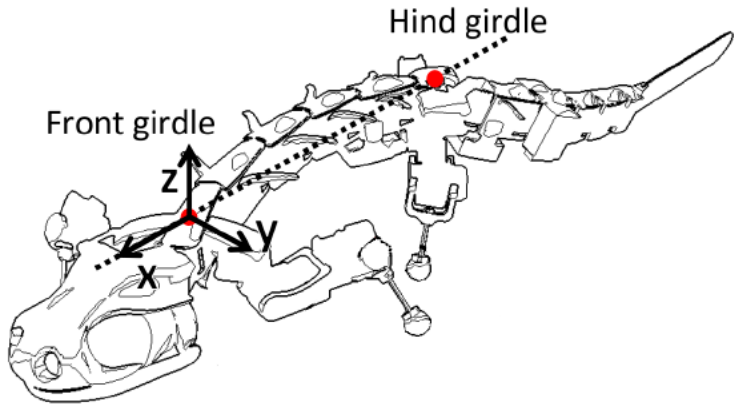
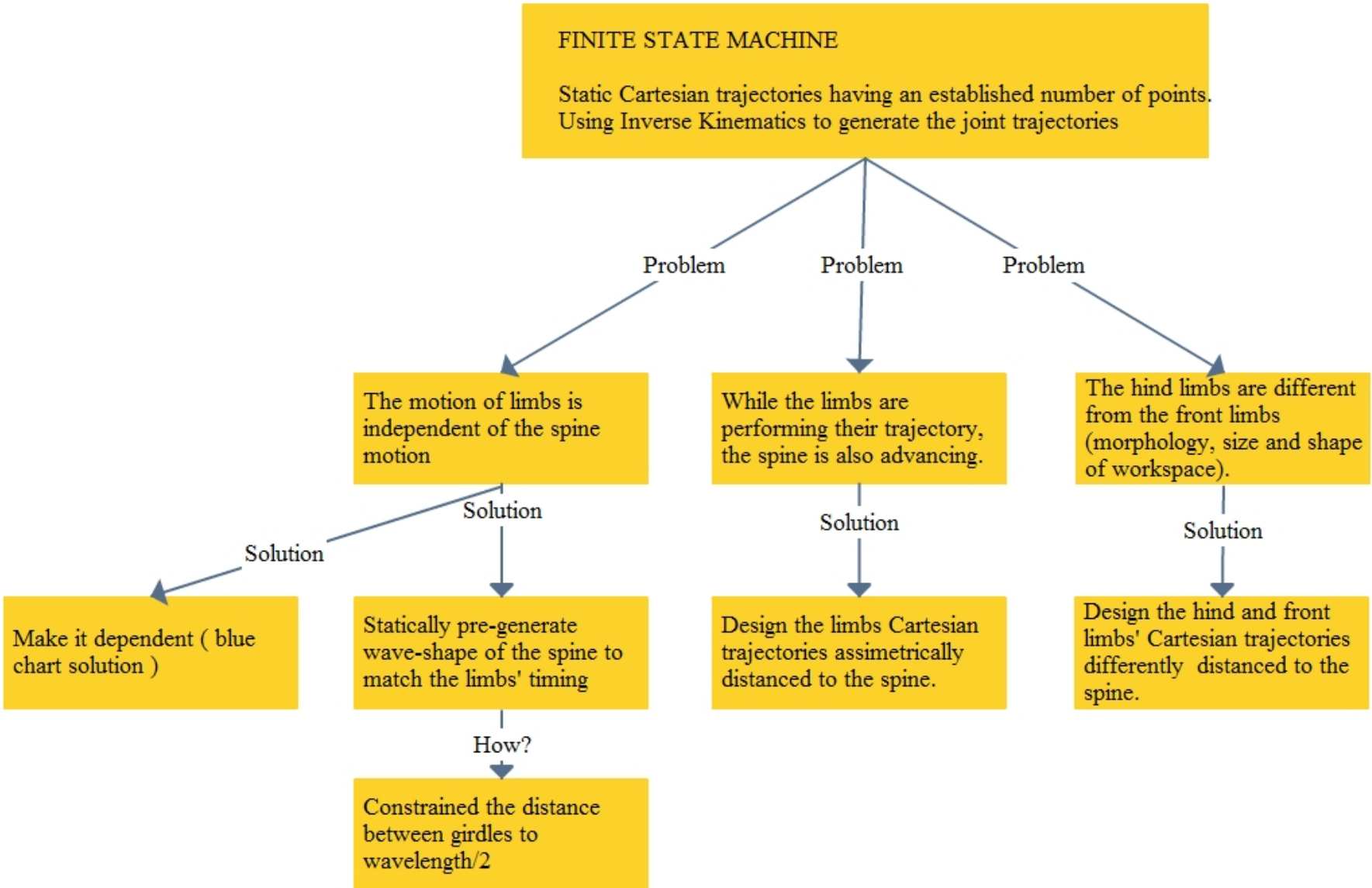


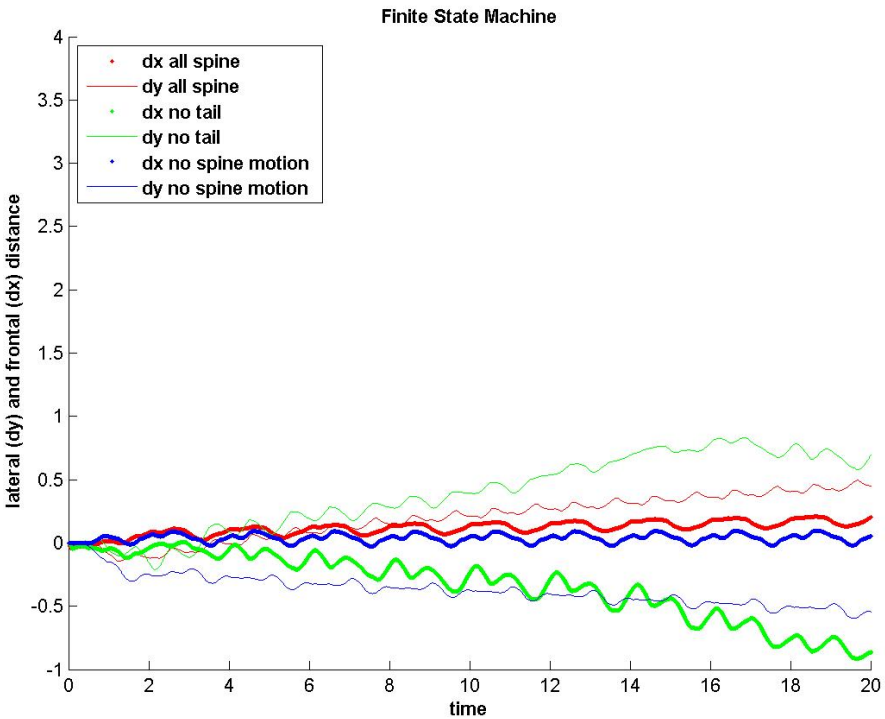
Figure 7: Coordinates system

Approach 1 - A State Machine

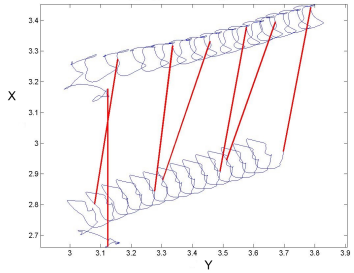


Method 1 - Influence of Spine

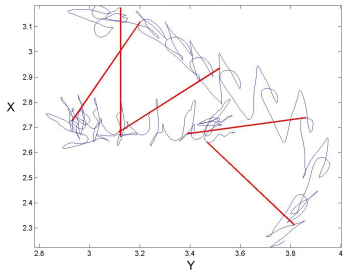
a) Comparative view



b)All spine and tail



c)Not using tail



d)Not using spine at all

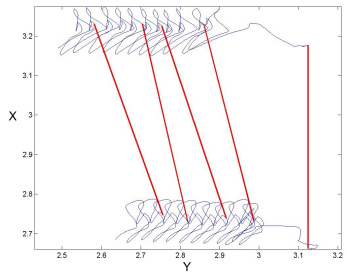
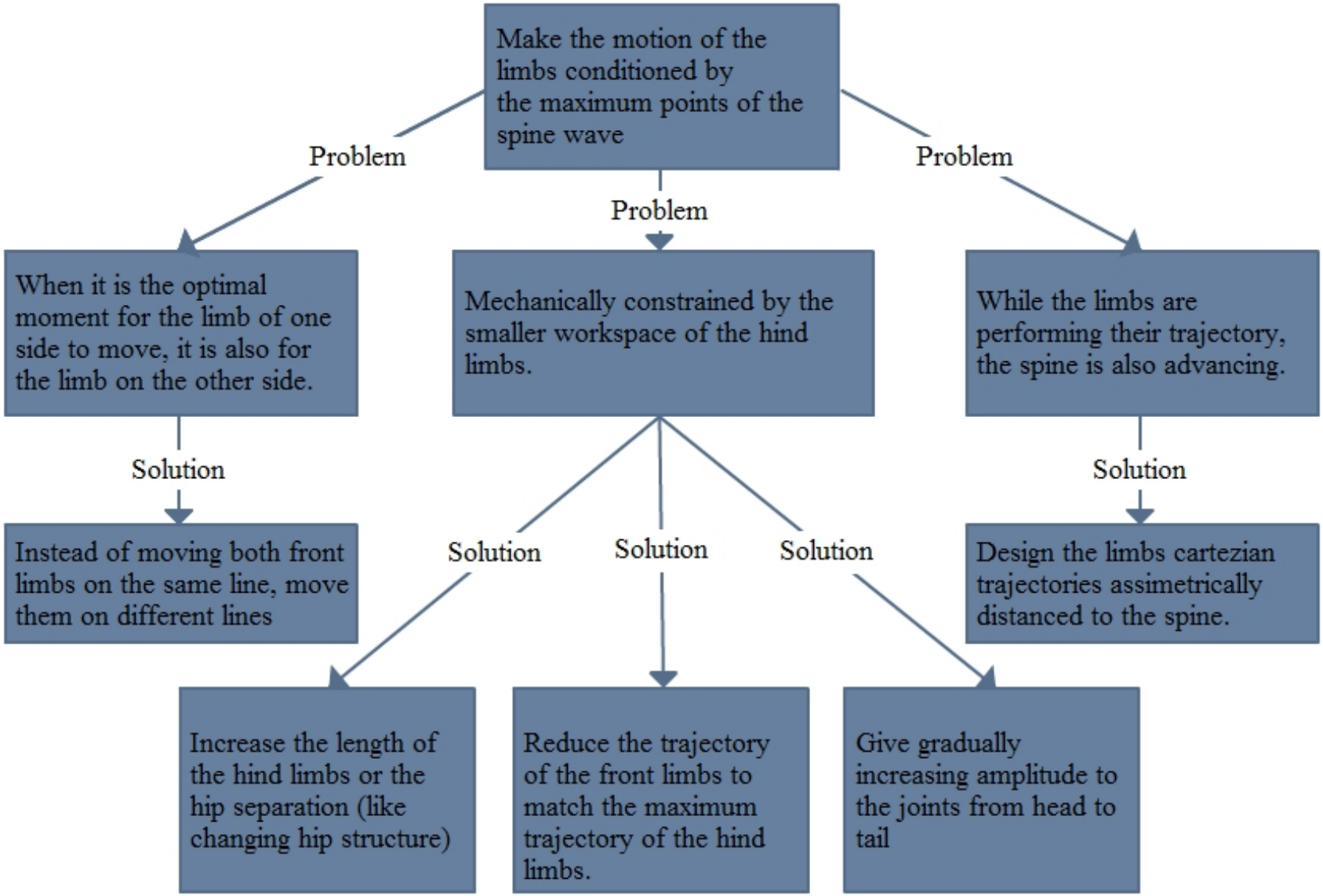


Figure 9: Influence of using spine on speed, trajectory and orientation

Play b) Play c) Play d)

Approach 2 - Move Side at Maximum Amplitude



Problems with This Approach

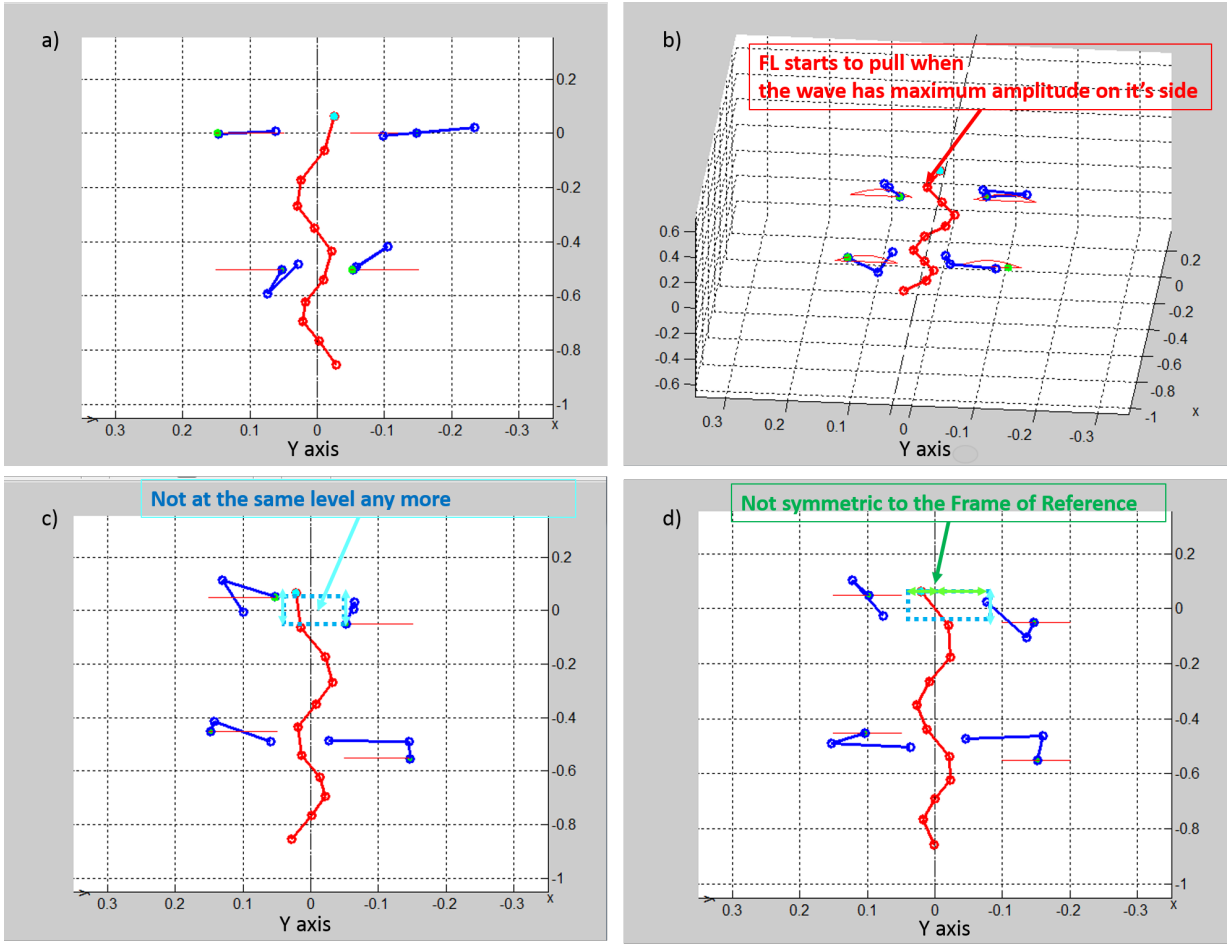
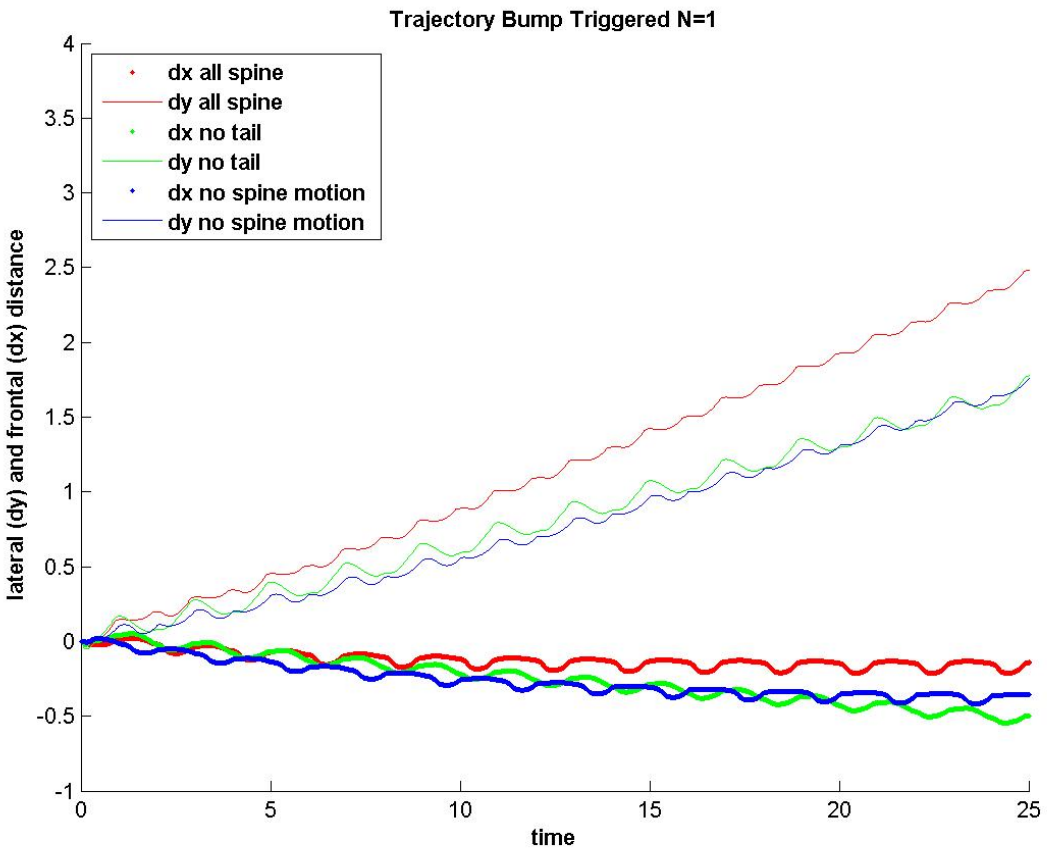


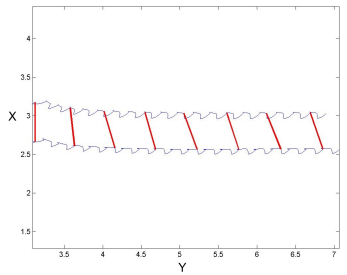
Figure 11: The chart presents different variations of the "Spine-Triggered" method

Method 2 - Influence of Spine

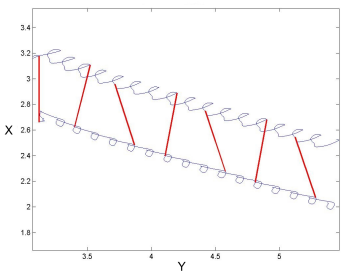
a) Comparative view



b)All spine and tail



c)Not using tail



d)Not using spine at all

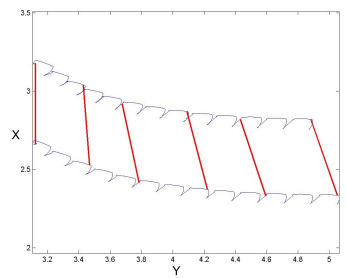
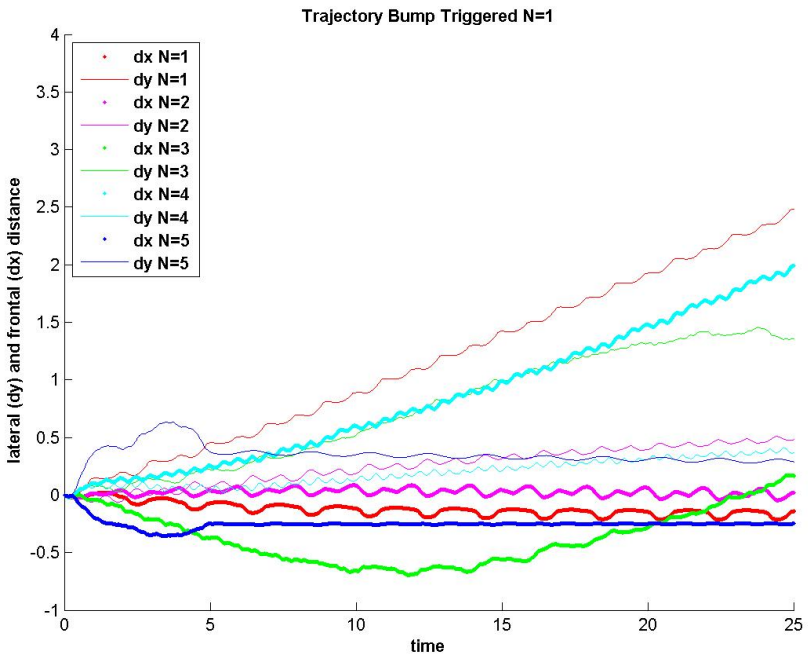


Figure 12: Influence of using spine on speed, trajectory and orientation

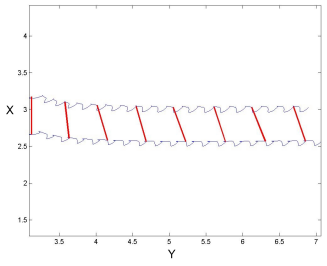
Play b) Play c) Play d)

Method 2 - Influence of Speed Ratio of Spine and Limbs

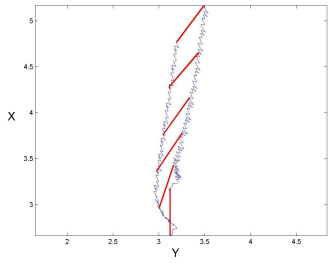
a) Comparative view



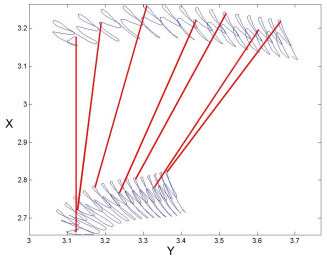
b) Ratio=1



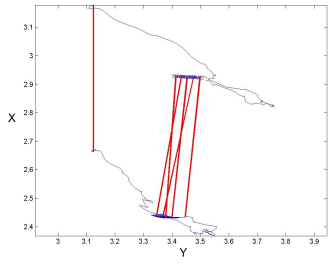
e) Ratio=4



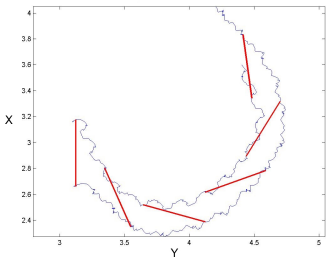
c) Ratio=2



f) Ratio=5



d)Ratio=3



Play b)

Play c)

Play d)

Play d)

Play e)

Figure 13: Chart a) comparative view and b) to f) orientation of the robot in time. Ratio 1 is the best so far but there is place for improvement

Approach 3 - Sinusoial Functions

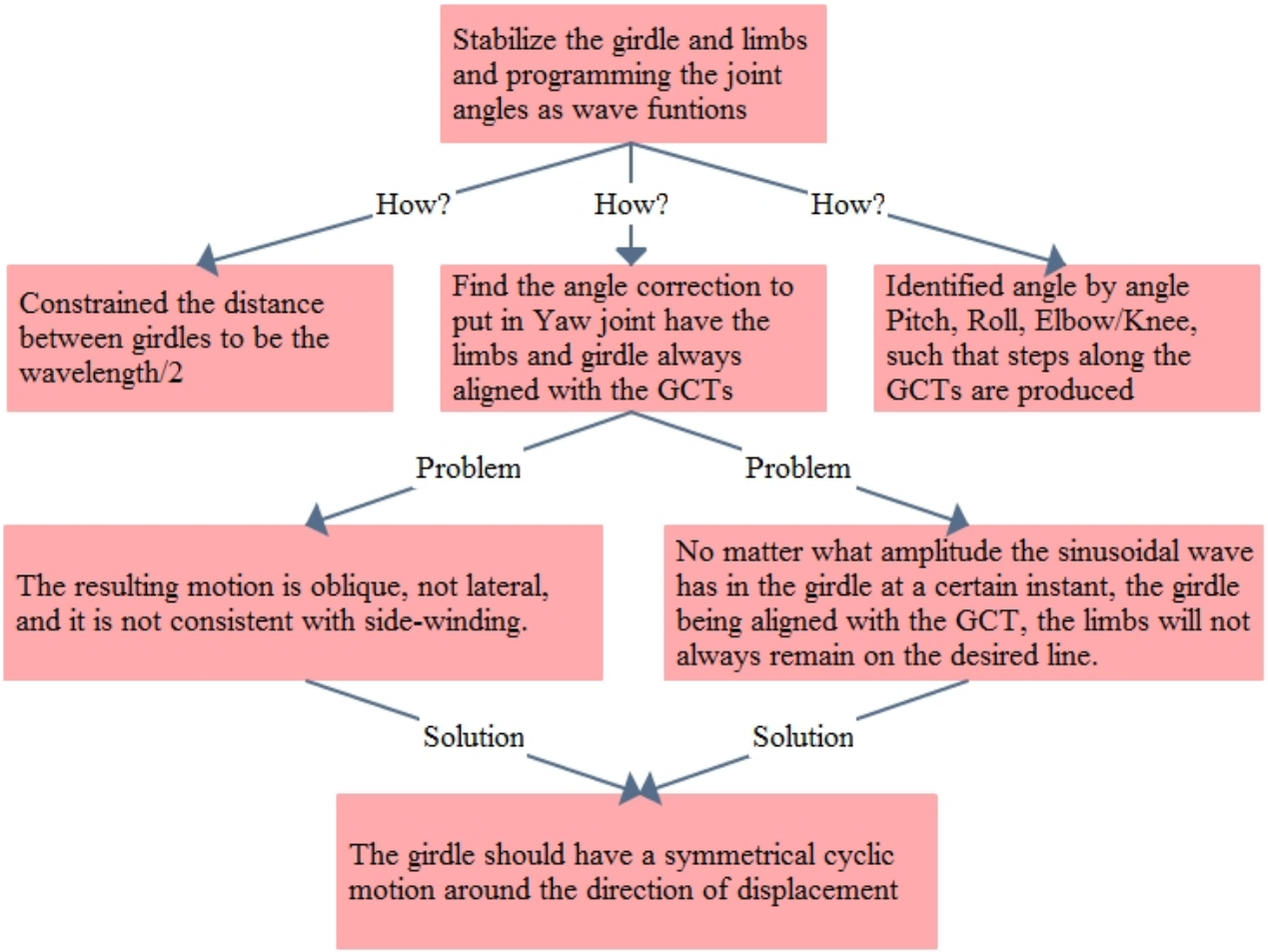


Figure 14: The chart presents different aspects related to the Wave Functions approach

Approach 3 - Sinusoidal Functions

Limbs vs. gaits	Yaw	Pitch	Roll	Knee-Elbow
Front Left	Front Girdle compensation -ρ	Equation 2	$\pi/2$	Θ_{Elbow} in Equation 3
Front Right	Front Girdle compensation -ρ	Equation 2	$\pi/2$	$-\Theta_{Elbow}$
Hind Left	Hind Girdle compensation -ρ	$0t$	$0t$	$-\pi/2 - scale\Theta_{Elbow}$
Hind Right	Hind Girdle compensation -ρ	$0t$	$0t$	$\pi/2 + scale\Theta_{Elbow}$

Table 1: Summary of the angles that have to be commanded directly to the joints

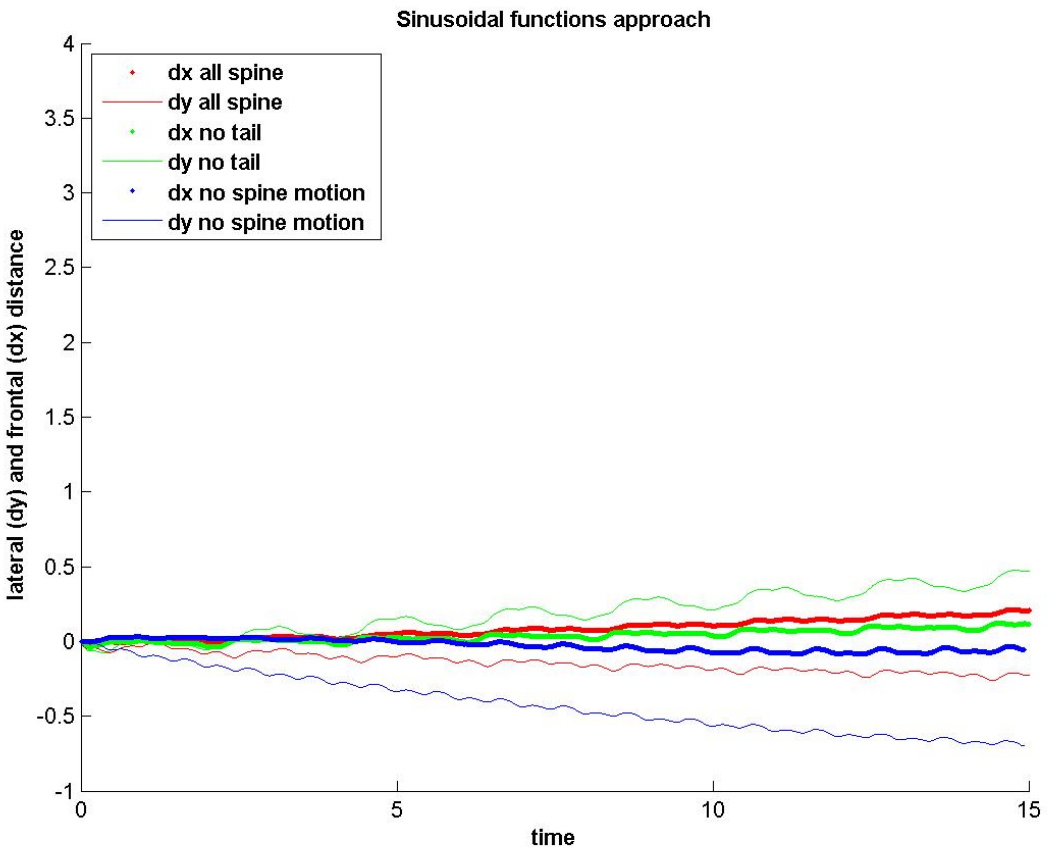
$$\Theta_{Pitch}(t) = A_{Pitch} Sin(\omega t + \Phi_{Pitch}) \tag{2}$$

$$\Theta_{Elbow}(t) = -A_{Elbow} Sin(\omega t + \Phi_{Elbow}) \tag{3}$$

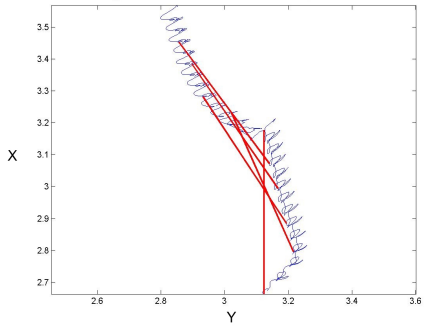
Where: $\begin{cases} A_{Elbow} = 3\pi/18; & A_{Pitch} = \pi/18; \\ \Phi_{Elbow} = \pi/4; & \Phi_{Pitch} = \pi/4; scale = 0.55. \end{cases}$

Method 3 - Influence of Spine

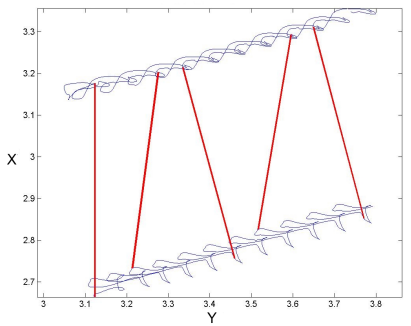
a) Comparative view



b)All spine and tail



c)Not using tail



d)Not using spine at all

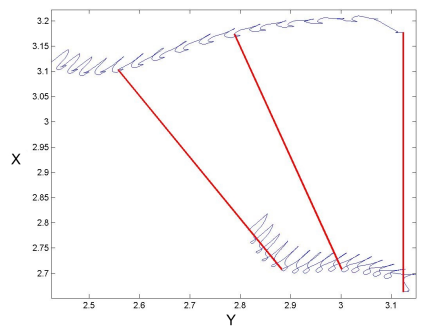
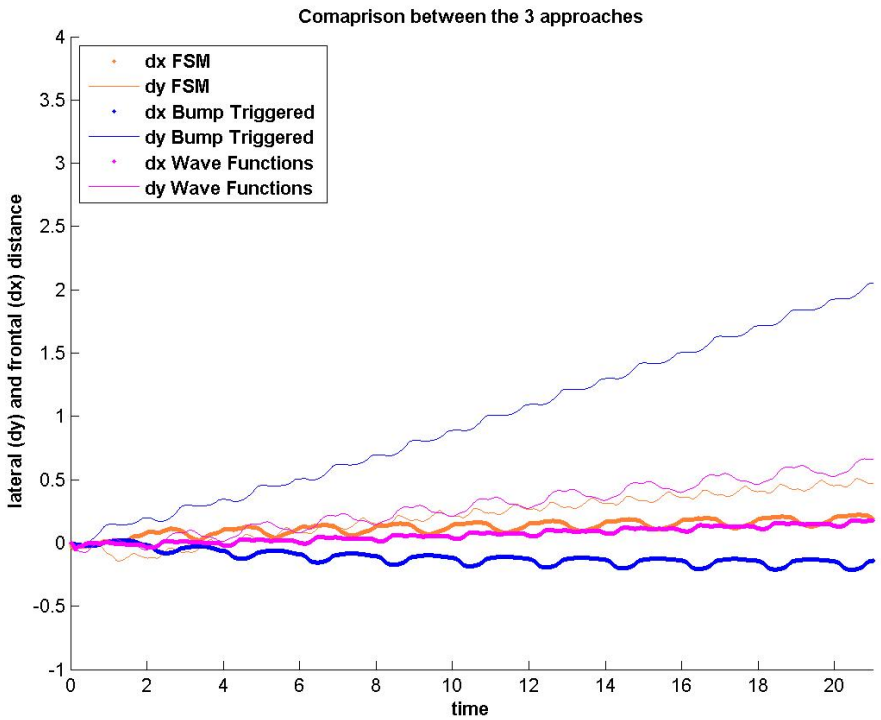


Figure 15: Influence of using spine on speed, trajectory and orientation

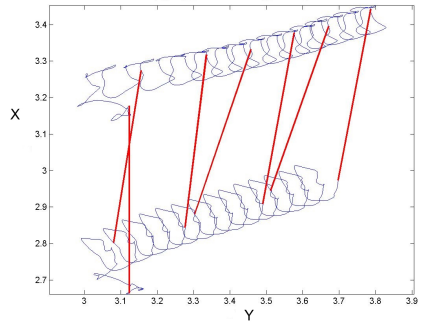
Play b) Play c) Play d)

Comparing Methods

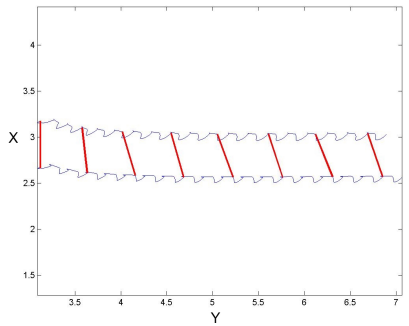
a) Comparative view



b)State Machine



c)Side walk



d)Sinusoidal functions

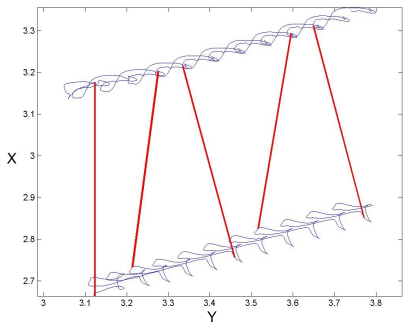
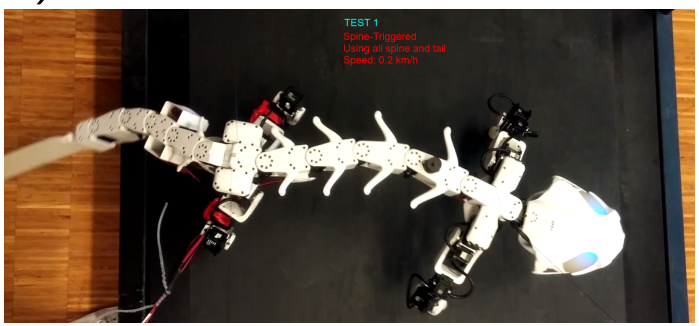


Figure 16: Comparison view between the best gait of each approach: b)Approach 1, c)Approach 2, d)Approach 3

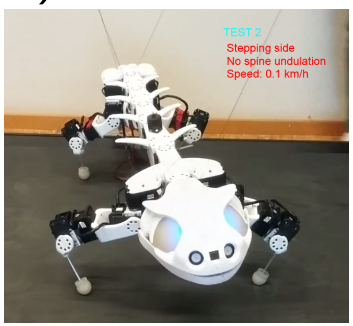
Play b) Play c) Play d)

Practical Implementation

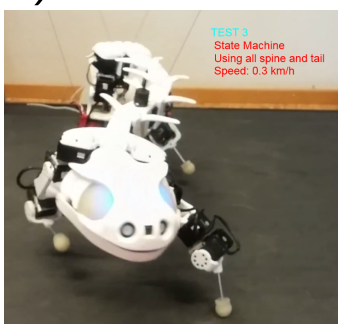
a) Test 1



b) Test 2



c) Test 3



d) Test 4

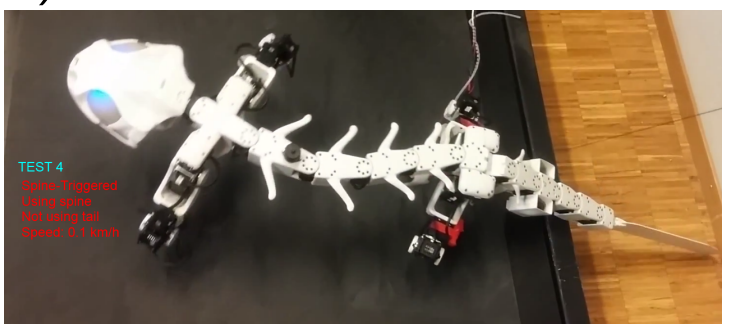


Figure 17: Tests on Pleurobot

SM all spine | Side all spine | Side no tail | Side no spine

Contents

Conclusions - The Question

How can the 4 DOF limbs be exploited, to produce the vertical wave effect present in the snake's spine?

- Stepping
- Putting waves in joints

Conclusions

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4. The tail is an important parameter to consider in the case of side-winding, and, in most cases, it should be used.
5. The ratio of speed between the limbs and spine can not be varied
6. Side-walking is the best, but the others might also be if tuned.

Further Steps

Morphologically, the following things might be done:

- Adding extra limbs
- Adding wheels. This would enable slipping
- A few of the 11 joints of the spine with the capability of vertical bending.

Contents

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Questions?