

Propulsion methods for underwater snake robots

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Introduction

Snake robots seems to have a promising future due to the flexibility and property to maneuver in confined environment. The Norwegian University of Science and Technology (NTNU) and SINTEF started in 2003 a research program on snake robots. Most research have been on ground based snakes, but lately also underwater snakes has been investigated by NTNU. Maneuvering and transit of snake robots are an important topic in this respect. The aim for this thesis is to investigate propulsion methods for an underwater snake robot. Using the nature as inspiration, foil propulsion has been investigated together with the body motion of the snake robot to improve efficiency and speed characteristics.

Simulations

To solve the dynamic equations the ode23tb solver in Matlab was used with a relative and absolute error tolerance of 10^{-4} .

An eel like locomotion of the snake robot is achieved by controlling the joints to follow a desired angle. We can choose the amplitude, phase and frequency of the joint signal to create the locomotion we want. To control the joint angles to the reference angle, a PD controller is used.

The simulation is done with $n = 10$ links where each link have the length $2l = 2 \times 0.07\text{m}$. The cross section is assumed to be elliptical with the radius 0.05 and 0.03 m. The density is $\rho = 1000\text{ kg/m}^3$. Mass of each link then becomes $m = 0.6597\text{kg}$ if we assume that the snake is neutral buoyant.

A tail has been designed using a NACA0016 profile. The tail has height of 40 cm and a maximum cord length of 7.5 cm.

Simulations with and without tail have been done.

Method and modelling

The kinematics and dynamics of a snake like robot swimming in a 2D plan has been modeled. The snake consists of N links where each link has a length equal to $2l_i$, where i is the link number (see Figure 1). The links can have different mass, length and inertia but it is assumed that the center of mass is in the center of the link. The snake robot has $N-1$ motorized joints. To express the dynamics, the angular acceleration between the x axis and the link $\ddot{\theta}$ and the acceleration of the total mass center \ddot{P} . The following state space model is achieved and can be solved in Matlab, $\dot{\mathbf{x}} = [\dot{\theta}, \dot{P}, \ddot{\theta}, \ddot{P}]$.

The hydrodynamics of a swimming fish or eel are complex and still not completely understood. An exact model is therefore not possible to make. The most accurate way to calculate the fluid forces are CFD (Computational Fluid Dynamics) which means to solve the Navies Stokes equation numerically. The computational cost of such a method is extremely high and not suitable for real time control. We have therefore used the Morison equation to model the fluid forces including both the added mass, linear and non-linear drag considering that the snake robot is a slender body. Each link is considered as an isolated segment and the snake robot is approximated to have an elliptical cross section. The fluid forces are assumed to only be dependent on the transverse link motion.

A tail model is made using foil theory assuming that it is a flat plate oscillating. Both added mass and lift from the foil is included.

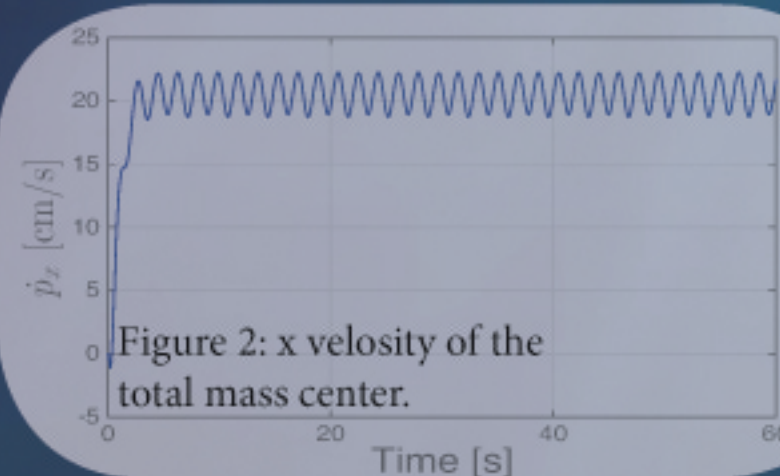


Figure 2: x velocity of the total mass center.

Results

Figure 2 shows the x velocity for the total mass center for the snake without tail. The simulations with tail are not completely finished.

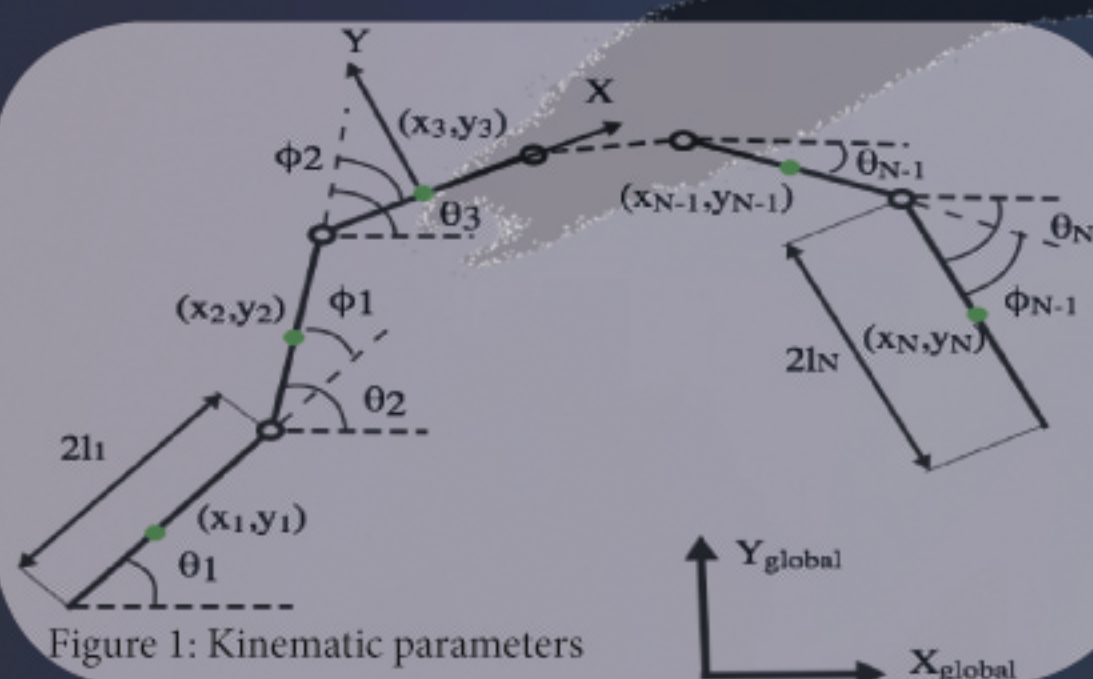


Figure 1: Kinematic parameters

Conclusion

A more general model of the existing model of an under water snakelike robot moving in a 2D plane has been created. In the extended model each link can have different mass, length and inertia and it is possible to include an extra propulsive force in each link. The new model has been simulated and validated against the already existing model, and they give the same results. The simulation with tail is not fully completed and is still to be verified. Some first result seems to be promising showing an improvement in the speed performance without any optimizing of the motion.