Printable Modular Robot

An Application of Rapid Prototyping for Flexible Robot Design

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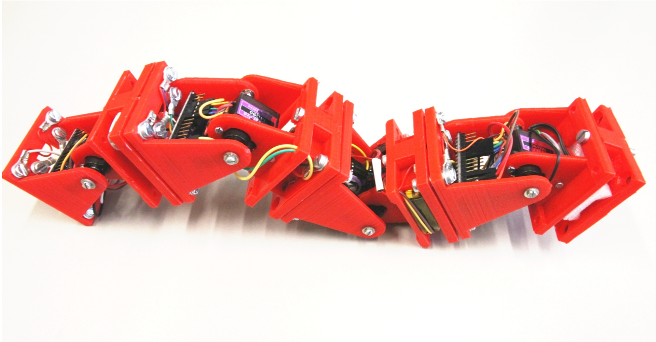
Table of Content

3D-Printable Modular Robot

PMR

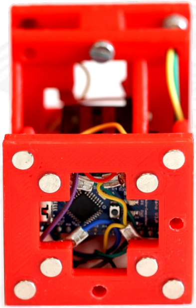


Prototype with 4 modules in pitching configuration.

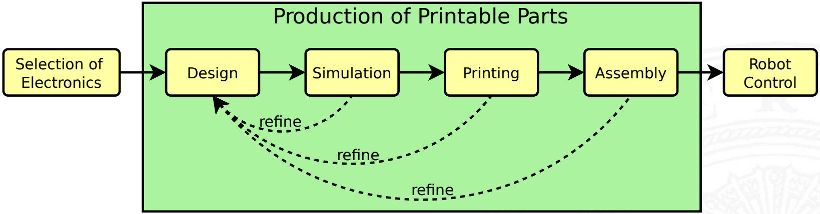
Robot

Specifications

- magnetic connection interfaces feature fast reconfiguration without tools
- fully distributed system (one `atmega328p` per module)
- suitable for research and education
- low-cost ($\approx$ 20$ per module)
- weight of $\leq$ 140g per module
- bluetooth connection for remote control
- distributed power supply



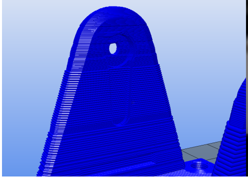
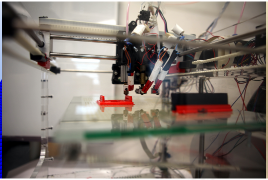
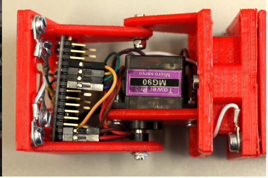
Workflow in Rapid Robot Prototyping



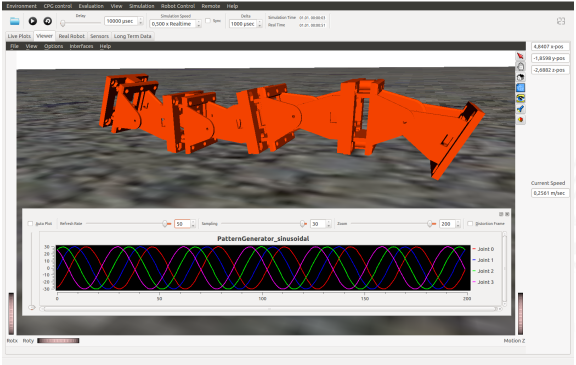
- selection of components determine the design of the robot
- production process contains many optional steps of refinement
- implementation of control depends on integrated components

Manufacturing Process

- fast and flexible manufacturing allows for adapting new components
- with CSG arbitrary standard components can be integrated in the design
- close coupling of design, production and simulation

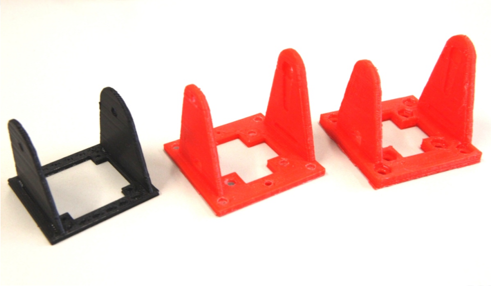
Simulation



- same 3D-models for printing and simulation
- evaluation of prototypes before manufacturing
- simulation based on ODE and OpenRAVE
- optimization of control parameters
- external locomotion generation

Evolution of plastic parts

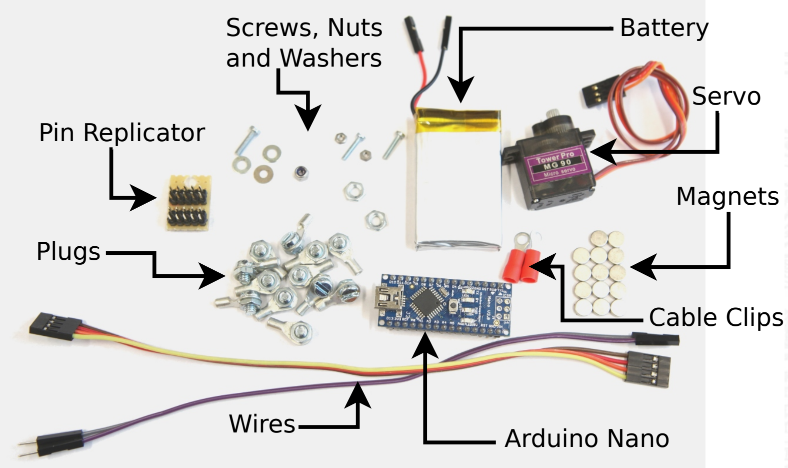
One of the housing parts at three different stages of the development



Integration of a factory into the office

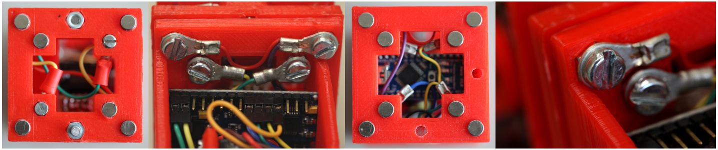
Since design and production occurs at the same place the time for development can be kept low.
$\Rightarrow$ Design problems can be eliminated at early stages.

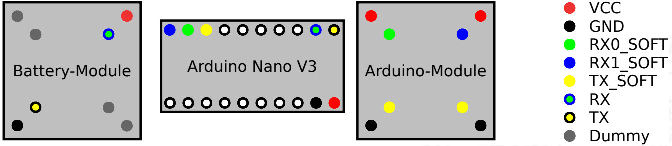
Standard components



Standard components

Connection interface

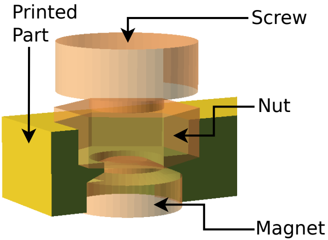




- magnetic connections allow for fast reconfiguration
- magnets are used for physical and electrical contacts
- reliability of communication lines is improved by ferromagnetic contacts that move slightly within the interface
- automatic orientation detection is provided by two different receive lines

Plug system

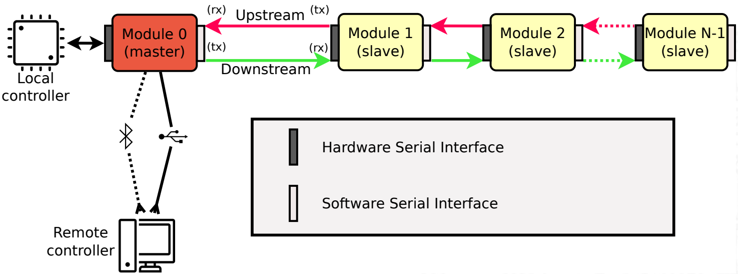
At the backside of the connection interfaces wires are mounted by using magnetic force.



- magnets and nuts fit perfectly into the printed part to make the connection physically robust
- magnetism increases the robustness against physical disturbances
- cable clips are placed between screws and nuts to create electrical contact between cable and magnets

Different levels of control

Overview



- inter-module communication
- low-level control
- high-level control

Different levels of control

Inter-module communication

- inter-module communication
  - our communication protocol uses cross-connected hardware- and software-UARTs
  - firmware of each module is based on arduino libraries
  - autonomous detection of newly connected modules and their orientation is implemented
  - heartbeat signals help to detect disconnections of previously connected modules
- low-level control from local controller
- high-level control by an external remote controller

Different levels of control

Low-level control

- inter-module communication
- low-level control from local controller
  - access to inter-module commands
  - every module can be accessed by its unique ID
  - locomotion is generated from external remote controllers or local controllers by using basic commands like `setAngle`
  - arbitrary algorithms can be used in this way
- high-level control by an external remote controller

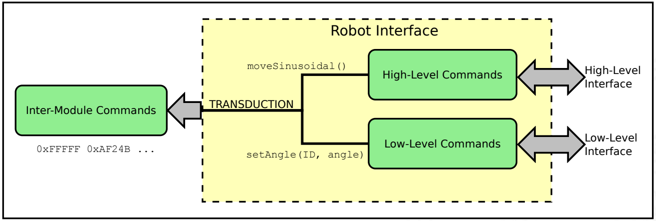
Different levels of control

High-level control

- inter-module communication
- low-level control from local controller
- high-level control by an external remote controller
  - commands e.g. to start stored locomotion procedures can be sent to the master via bluetooth or wired serial connection
  - available commands depend on the firmware of the robot
  - calibration, configuration and debugging is implemented

Different levels of control

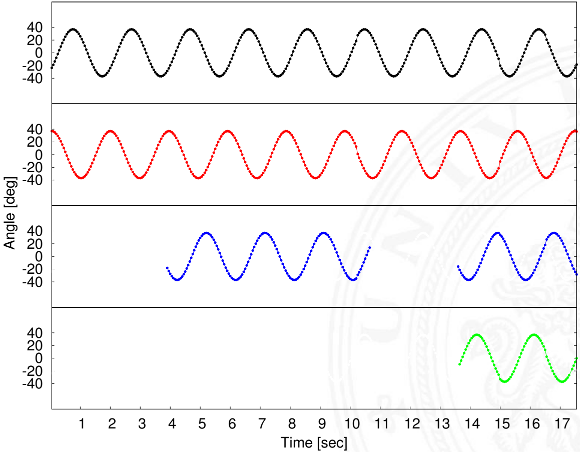
Summary



- additional external or local controllers utilize the low- or high-level interface to the robot
- execution of low- or high-level commands is internally translated to the robot's instruction set

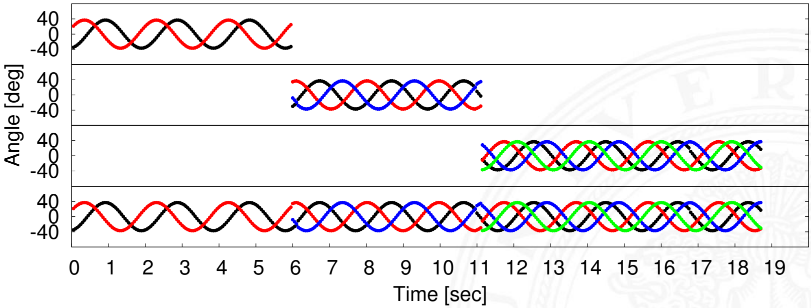
Locomotion

Fixed sinusoidal locomotion



Locomotion

Sinusoidal locomotion with adaptive phase difference



Automatic selection of phase difference depending on the number of currently connected modules.

Summary

Achieved goals:

- creation of an experimental, low-cost modular robot platform
- realization of a magnetic connection interface
- implementation of
  - ... a communication protocol based on UARTs
  - ... an automatic detection of topological reconfiguration
  - ... centralized and external locomotion generation

Future work

Next steps:

- implementation of distributed locomotion generation in order to reduce inter-module communication overhead
- implementation of new message type with nodewise acknowledges in order to avoid loosing messages
- integration of sensors
- development of new modules for additional robot topologies