Interactive Bacterial Evolutionary Algorithm for Work Pace Optimization of Cobots

Authors

Natabara Máté Gyöngyössy

Márk Domonkos

Dr. János Botzheim

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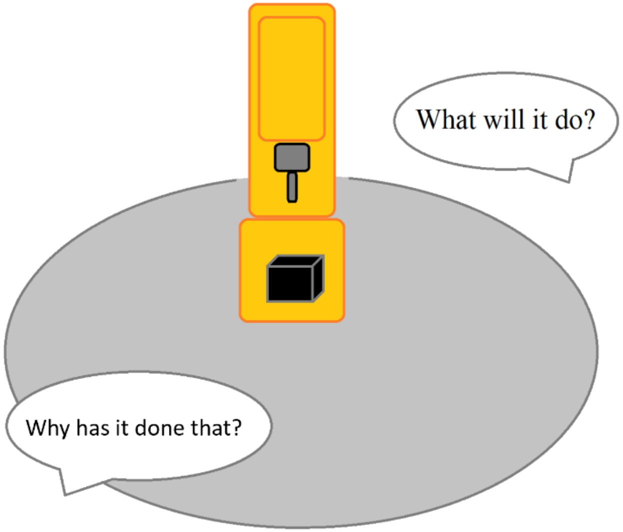
Introduction (1) – Robot as a black box

- First industrial robot made by Robert C. Devol, the UNIMATION
- Huge increase in performance
- Development of Cobots (Cooperative Robots)

https://www.plasticstoday.com/automation/five-things-consider-buying-cobot

https://artsandculture.google.com/asset/robot-first-unimate-robot-ever-installed-on-an-assembly-line-1961-devol-george-c-1912-2011/GQHHgKp0XejHeg

- In the majority of the applications the robots cannot communicate their inner state effectively → multiple types of danger (injuries, stress, productivity loss etc.)
- Robots are black-boxes from the perspective of the operators.

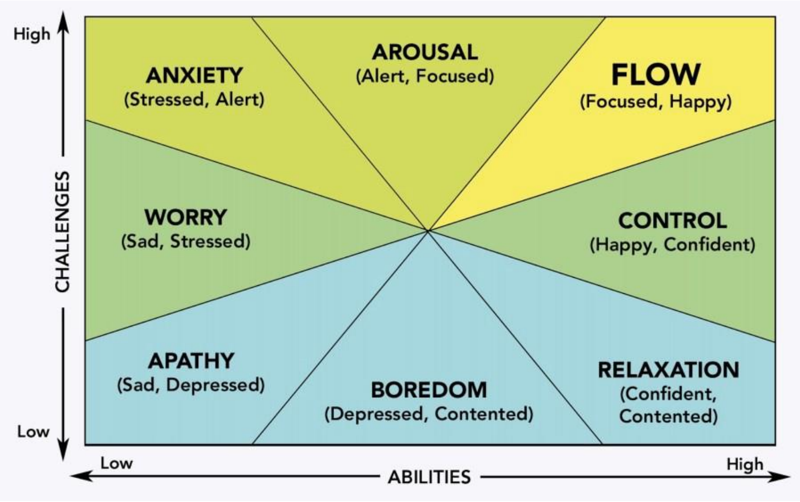


Introduction (2) – New problems in close cooperation

- Robots working in close cooperation needs to adjust their behavior
  - Internal factors (fatigue etc.)
  - External factors (fear from the robot etc.)
- External factors can be improved by a sophisticated robot behavior
  - Velocity
  - Acceleration
  - Time of immobility
  - Trajectory type

Process time

Achieve the optimal level of stress to achieve the flow state



https://uxdesign.cc/getting-into-the-flow-what-does-that-even-mean-58b16642ef1d

Introduction (3) – Work pace

- Robot + Operator = increase in productivity in many cases
- Work pace is essential!
  - A higher skilled operator can feel boring (and stressed) with an optimal pace of a lower skilled operator. On the other hand a lower skilled operator will face fatigue (and stress).
  - The work pace need of an individual can alter also during the day.

https://theconversation.com/why-boredom-can-be-good-for-you-90429

Both case can lead to increase in stress and thus in deficit in productivity

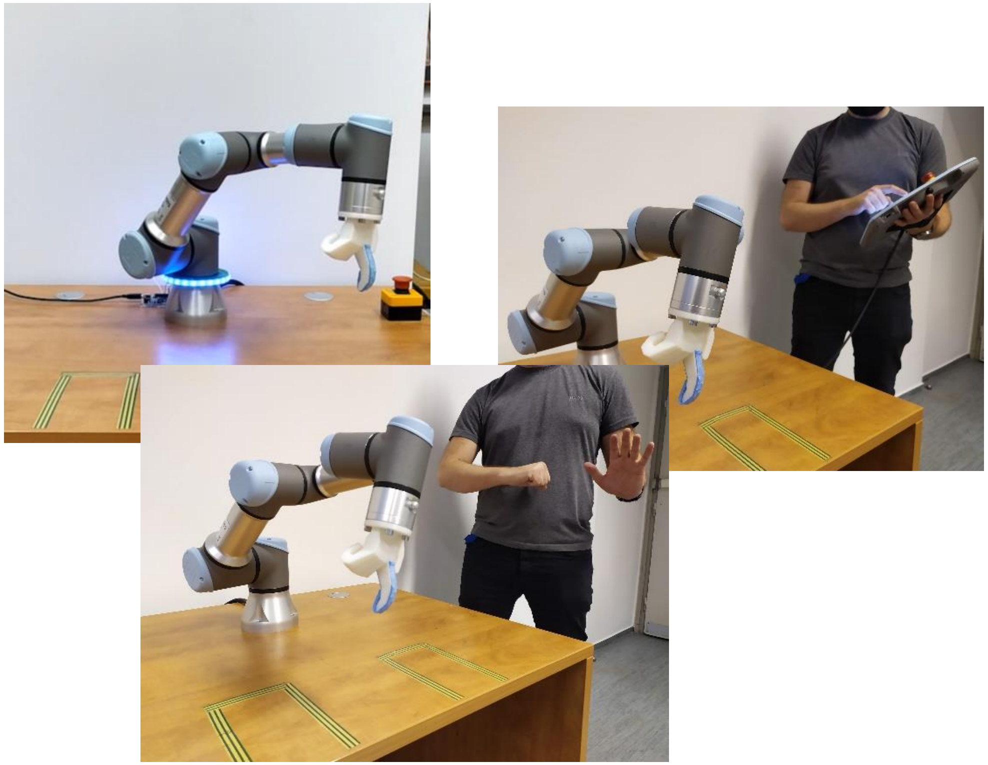
Bacterial Evolutionary Algorithm

https://ideascale.com/impact-of-stress-on-innovation/

Problem Statement (1) – Problem with cobot applications

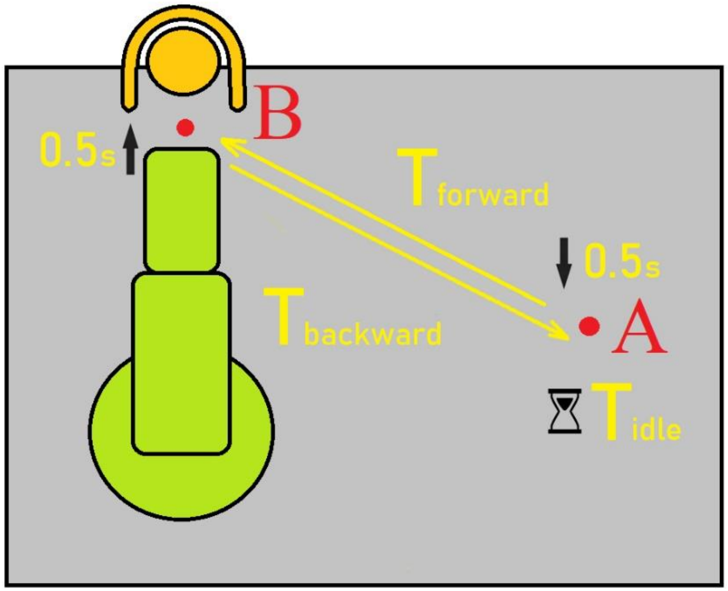
- Most of the cobot applications are low level applications in terms of interactivity
- Applications lack proper HRI and robot teaching
- Kuka iiwa robot as a „third hand” etc.

https://robots.ieee.org/robots/lbriiwa/



Problem Statement (2) - Implemented scenario

- Hand in task as initial test
  - Plastic workpiece quality check
- Simplified scenario
- A, B, and 2 points 10 cm above them
- Vertical movement has fixed time of 0.5s
- 3 variables:
  - $T_{forward}$
  - $T_{backward}$
  - T_{idle}
  - Each variable is in the range of [0.2; 2) s with a 0.1 s resolution
  - 5832 variations



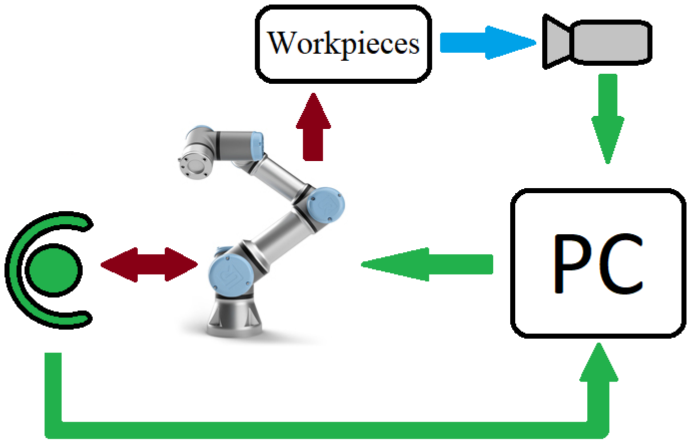
Bacterial Evolutionary Algorithm

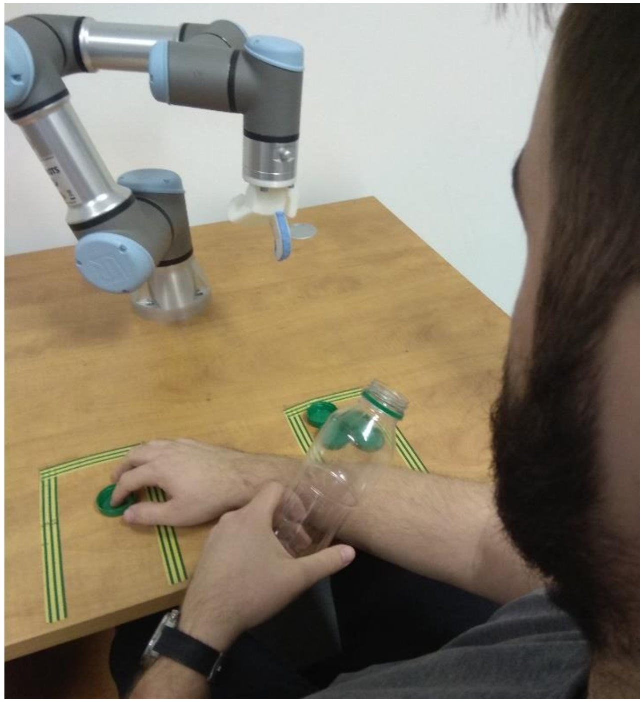
From human:
- Simple feedback
- HRV

From task:
- Total time

Problem Statement (3) - Experimental setup

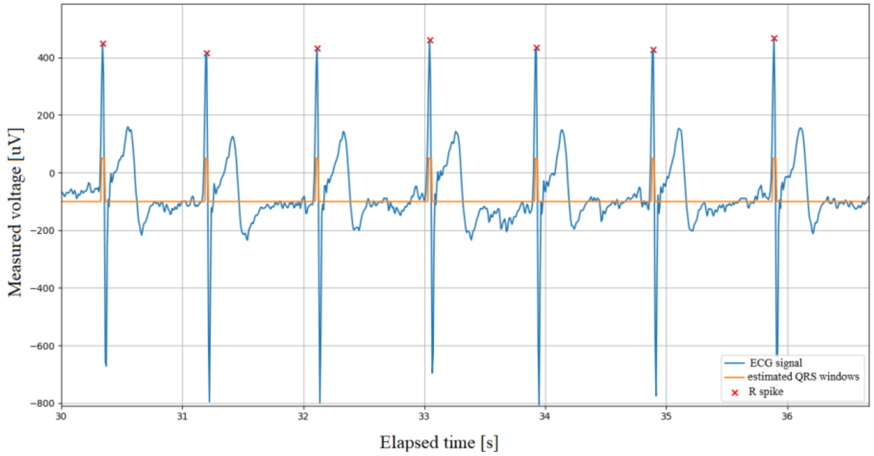
- UR3e collaborative robot
- 3D printed hand
- Basler ACA800-510UC + f6mm objective
- Plastic bottle + caps

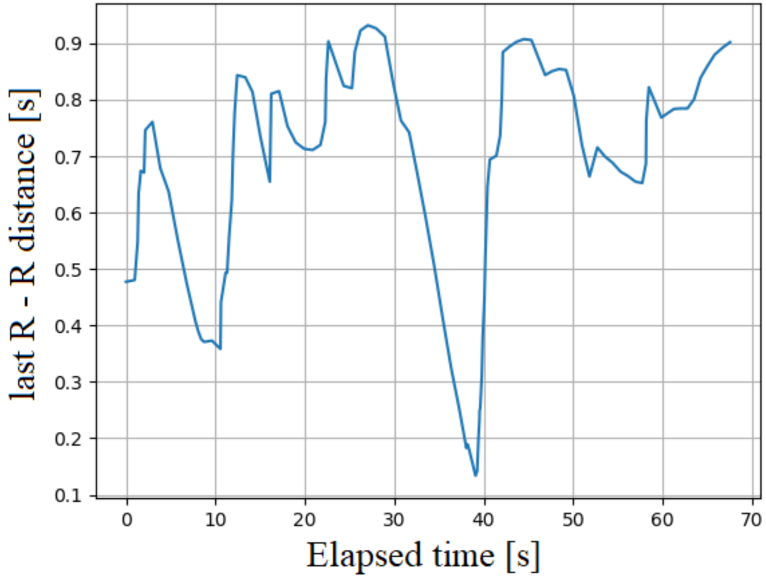




- 5 repetitions of task
- 1.5 min

Problem Statement (3) - Experimental setup



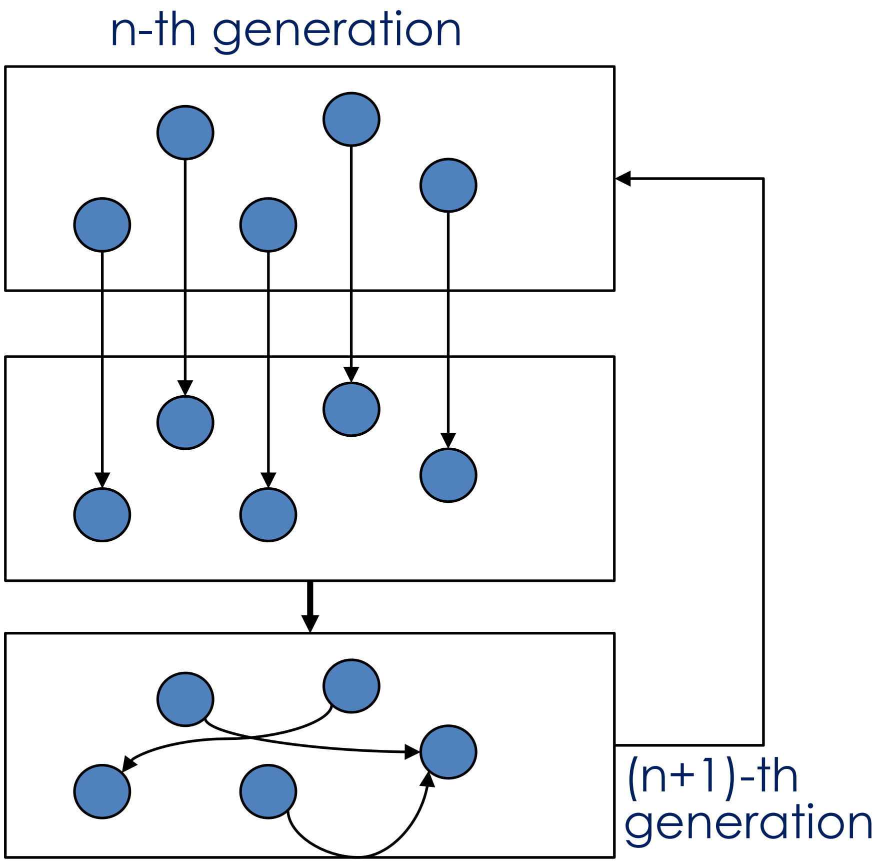


- Polar H10 sport belt
- After processing the ECG signals, the R-R distances are calculated as an input for the algorithm

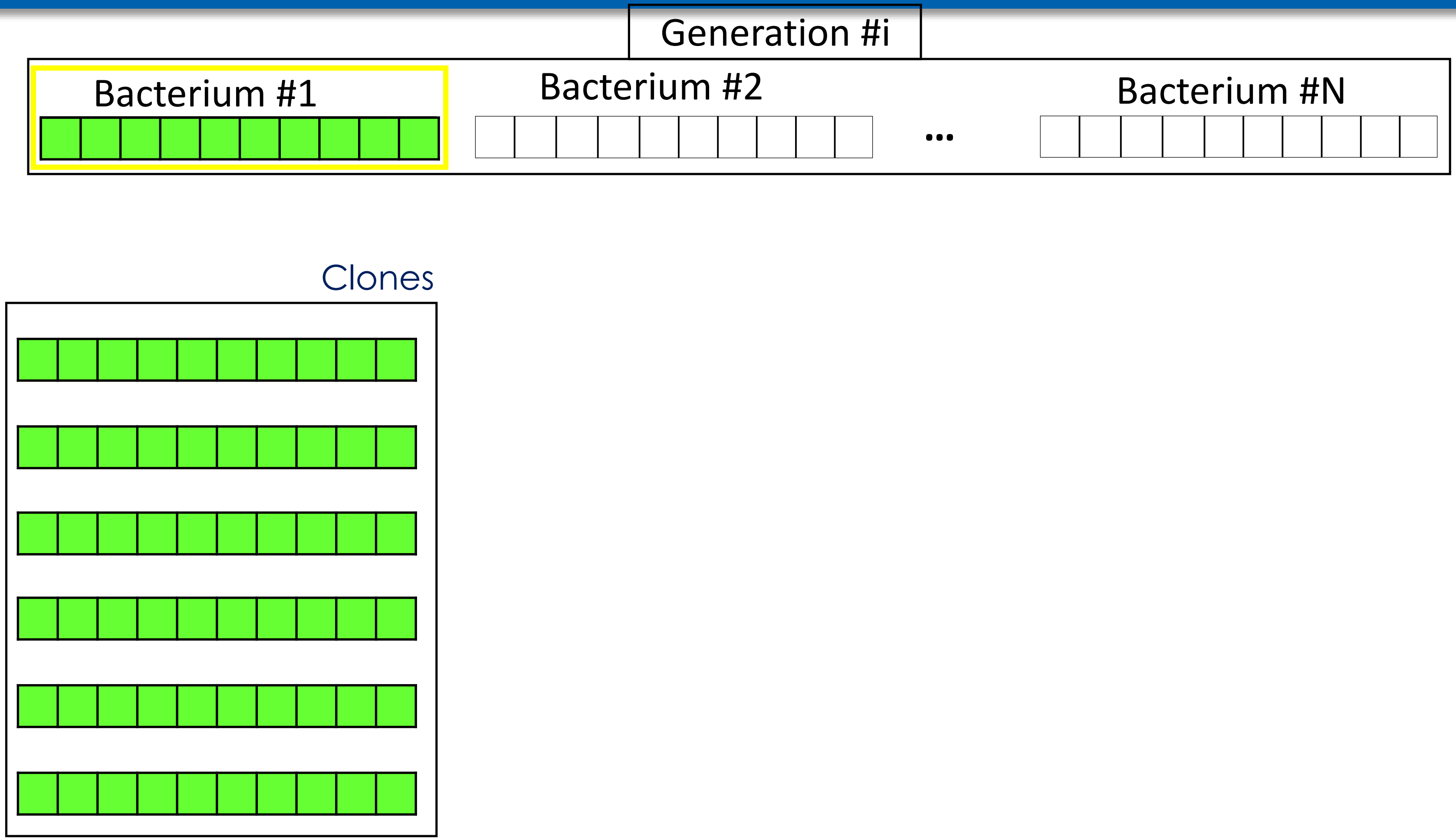
Problem Statement (4) - Experimental setup

Bacterial evolutionary algorithm

- Generating the initial population randomly
- Bacterial mutation is applied for each bacterium
- Gene transfer is applied in the population
- If a stopping condition is fulfilled then the algorithm stops, otherwise it continues with the bacterial mutation step



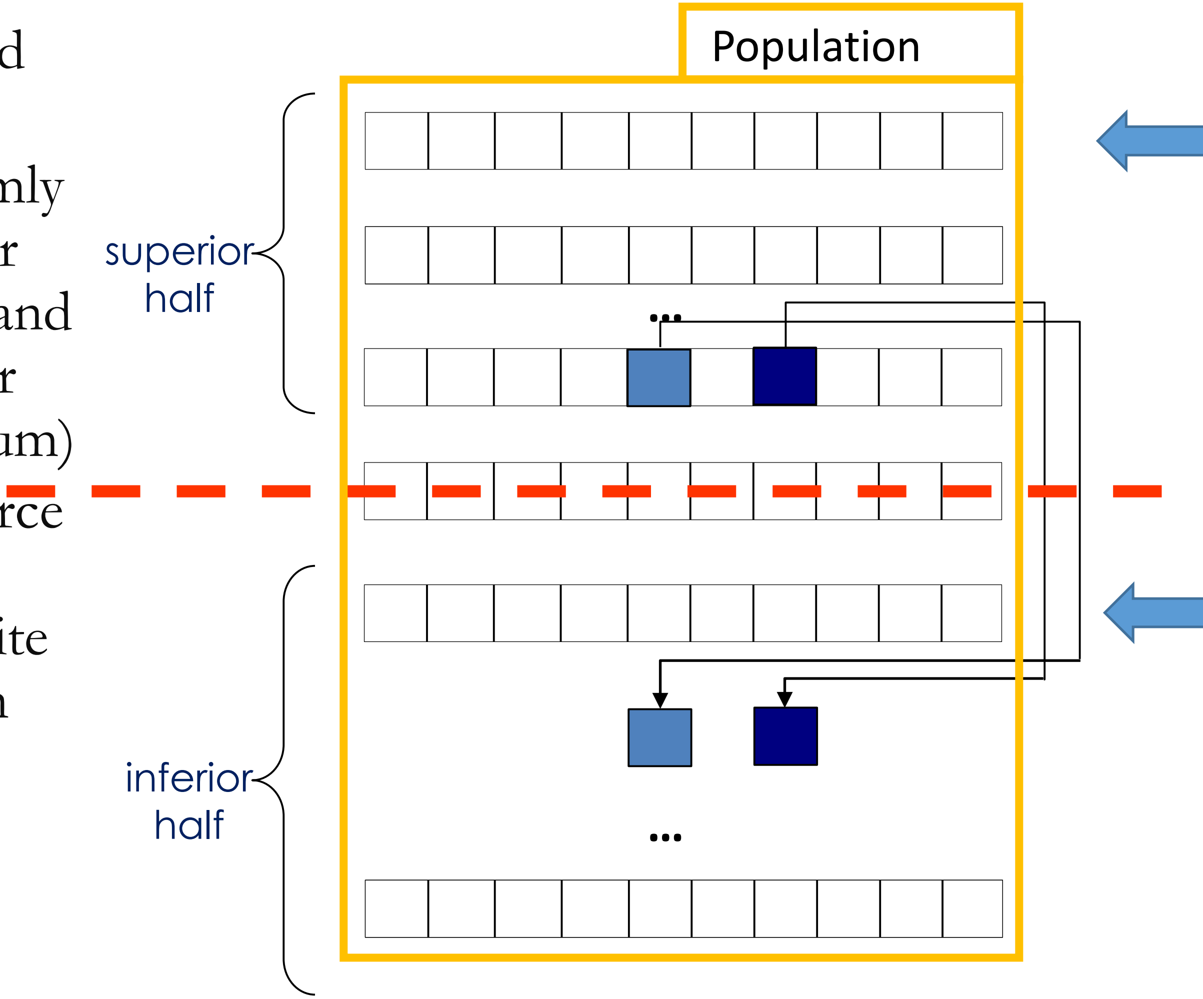
Bacterial mutation



Gene transfer

1. The population is divided into two halves
2. One bacterium is randomly chosen from the superior half (source bacterium) and another from the inferior half (destination bacterium)
3. A segment from the source bacterium is chosen and this segment can overwrite a part of the destination bacterium

This cycle is repeated N_{inf} times (number of “infections”)



Proposed algorithm - Novelties

- Probabilistic bacterial mutation:
  - The bacterial mutation operator is applied by a given probability to each individual.
- Interactivity in the fitness evaluation:
  - In interactive evolutionary algorithms the fitness value of the individuals is determined by a human.
  - We combine the human's subjective evaluation with other objective, measurable values in the fitness calculation.
  - The fitness of an individual is calculated as:

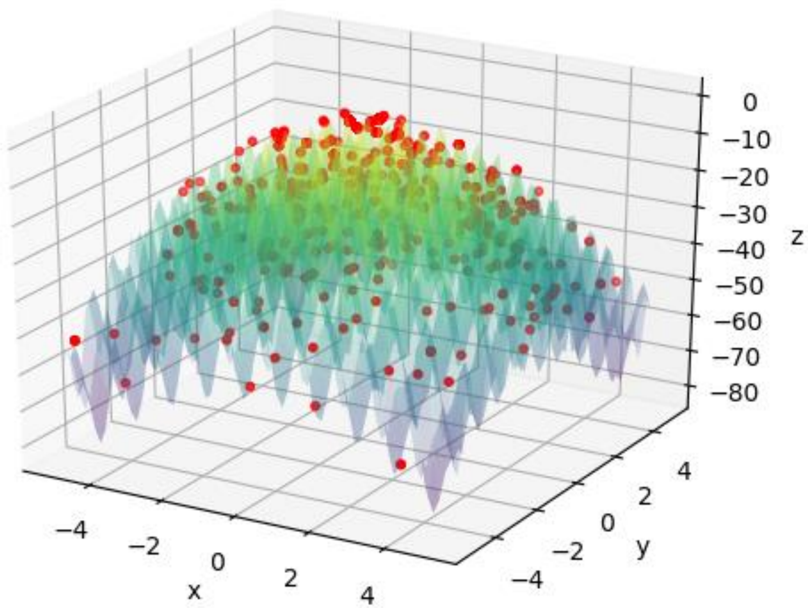
$$fitness = SF - 10\frac{\left|RR_{ref} - \overline{RR}\right|}{RR_{ref}} - \frac{CT}{2}$$

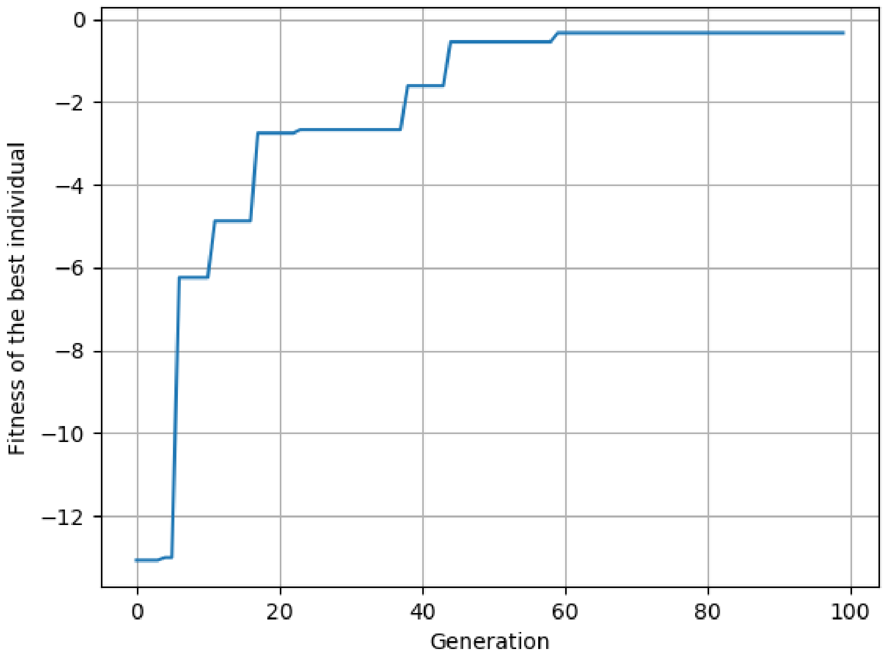
  - *SF* is the subjective feeling points (between 1 (worst) and 10 (best))
  - RR_{ref} is the reference R to R distance measured before the experiment
  - $\overline{RR}$ is the mean of the R to R distances
  - CT is the cycletime: $CT = T_{forward} + T_{backward} + T_{idle}$

Experimental Results (1) - Rastrigin

Benchmark function: Rastrigin function

- Continuous domain: $[-5.12, 5.12] \times [-5.12, 5.12]$
- Huge amount of local minima

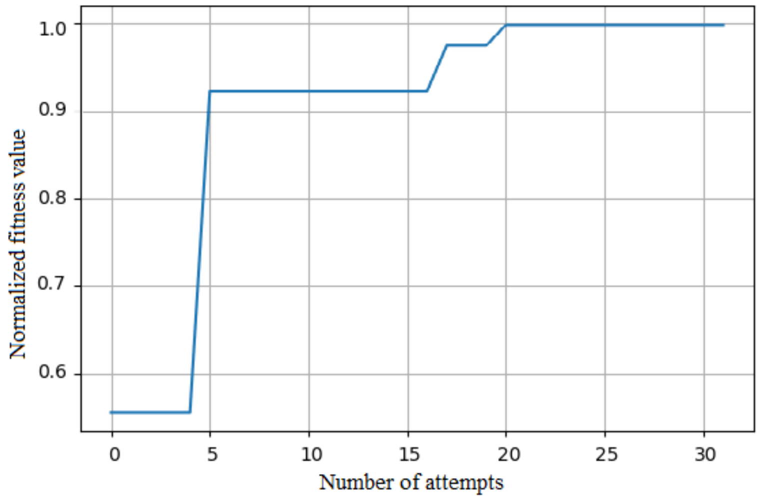


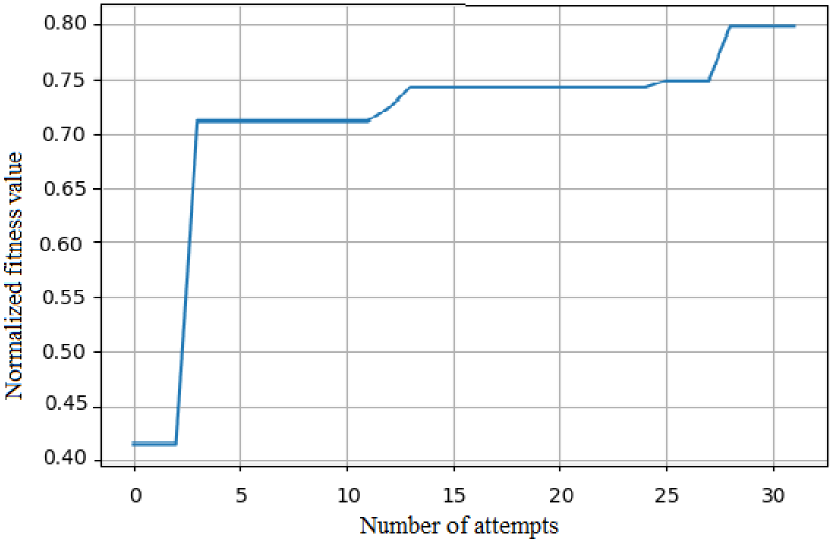


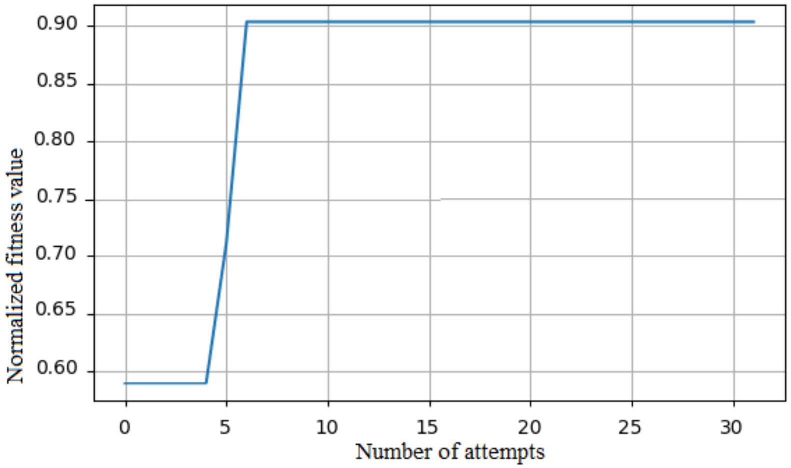
Algorithm parameters:

- Number of generations: 100
- Number of individuals: 20
- Probability of mutation: 0.2
- 3 mutated clones and 10 infections in bacterial mutation and in gene transfer operation respectively

Experimental Results (2) - Workpace







Three measurements

Conclusions

- In this paper an interactive bacterial evolutionary algorithm with probabilistic bacterial mutation was proposed for solving the work pace optimization problem.
- In the fitness evaluation subjective feeling is used based on the human operator's feedback and physically measured heart rate information as well.
- The proposed method could realize a smooth cooperation between the human and the robot.

- In the future work we will attempt to use additional information in the human's feedback such as verbal information which could possibly be described by fuzzy sets, and other types of sensory information for the better measurement of the stress level of human operators.

Thank you for your attention!