Design Principles for Cooperative Robots with Uncertainty-Aware and Resource-Wise Adaptive Behavior

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Abstract: In this paper we describe several principles for designing and implementing bio-inspired robotic collaborative search strategies. The design approach is particularly oriented for algorithms that can tackle search problems that deal with uncertainty, such as locating odor sources that have spatial and temporal variance. These kind of problems can be solved more efficiently by a reasonable amount of collaborative robots, and thus we propose a low-cost platform based on the open-source philosophy. The platform allows to evaluate different collective strategies that emerge from the interaction among robots that are aware of the uncertainty and make a wise use of all available sensors and resources. This includes an adaptive use of sensor signals and actuators, and a good communication strategy.
We introduce GNBot, a flexible open-source robotic platform, and a virtual communication network topology approach to validate uncertainty-aware and resource wise bio-inspired search strategies.

`Design files and documentation: http://github.com/carlosgs/GNBot`

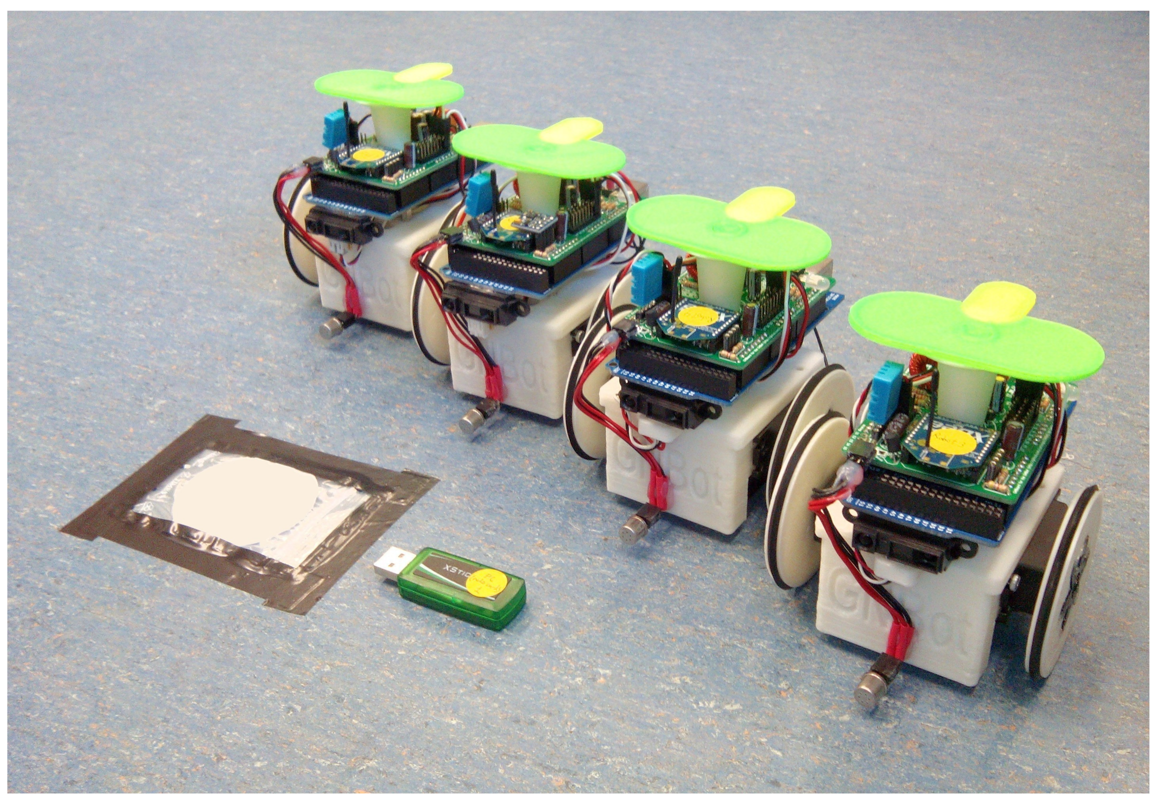


Fig 1: Four-robot swarm of GNBots

1. Collaborative robots for odor localization under uncertainty

Whilst simulated environments are often successfully used to demonstrate the performance of generic search tasks, the chaotic nature of gases and odor plumes often create a poor balance between the accuracy and computational requirements of the models. Thus, it is important to step out of simulations and have a way to actually test odor search algorithms in the real world.

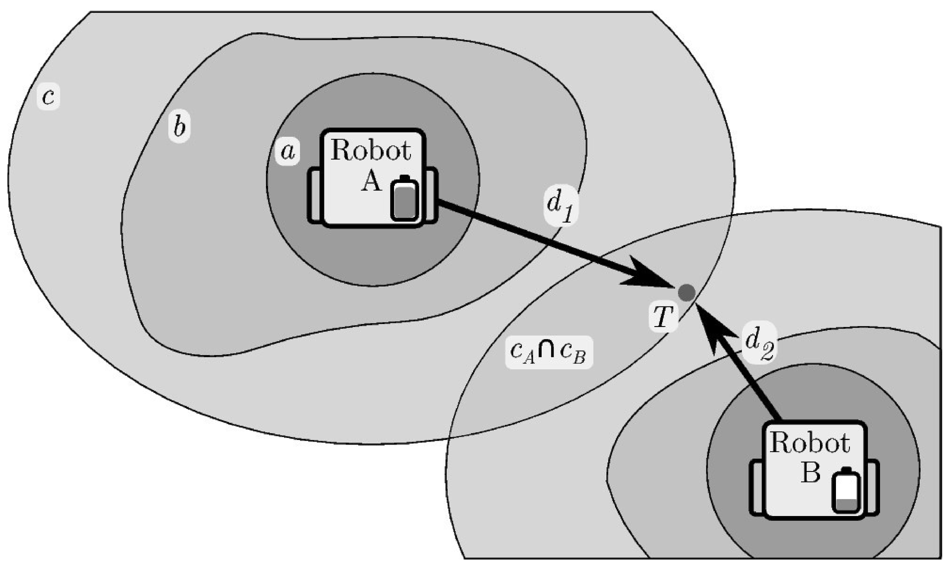
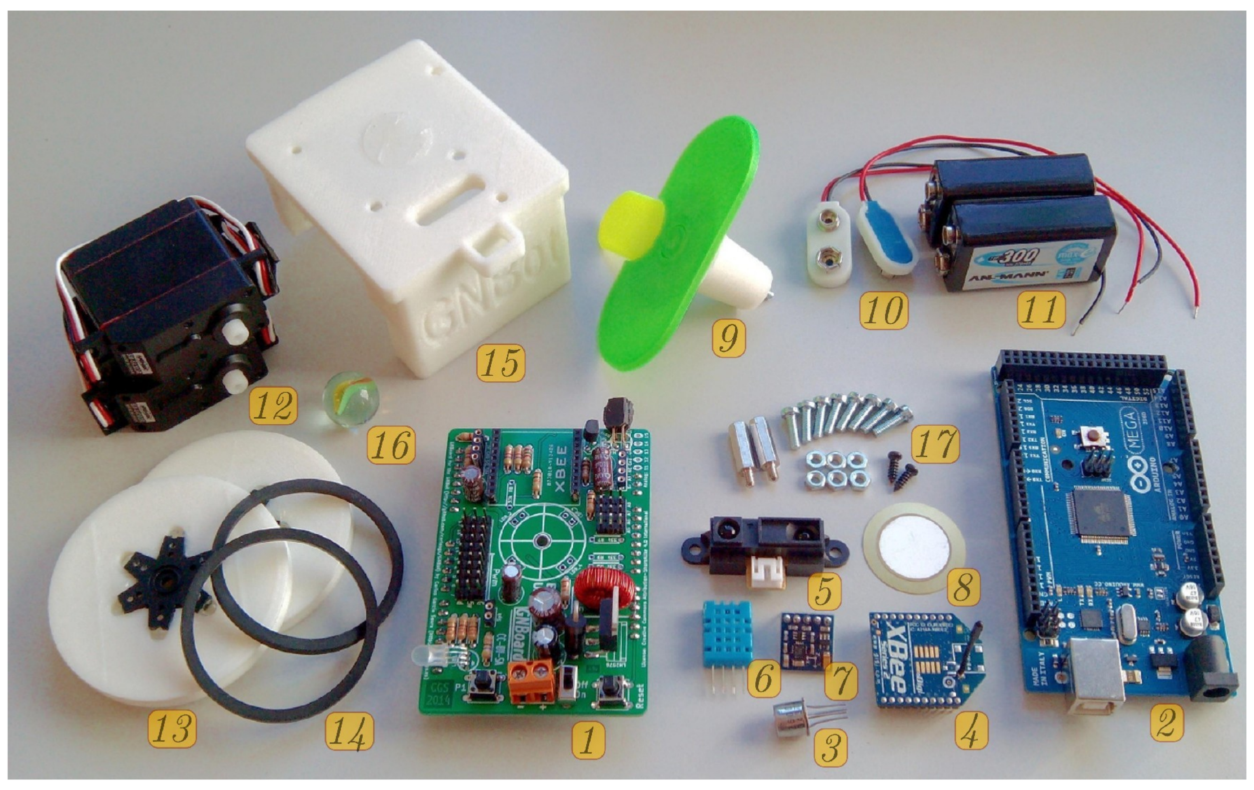


Fig 2: Resource-wise decision making

Also, the uncertainty inherent to the problem of odor localization seems to make possible a drastic reduction in the completion time by parallelizing the search with more than a single agent.

Here is where the cooperation among robots comes into play, as it is possible to implement a wide range of collaborative search algorithms that include centralized, de-centralized and distributed approaches.

2. Flexible swarm-ready robotic platform



1) GNBoard electronics
2) Arduino MEGA board
3) Odor sensor (*TGS-2600*)
4) RF module (*ZigBee*)
5) Infra-red distance sensor
6) Temp. and hum. sensor
7) Magnetometer (*HMC5883L*)
8) Piezoelectric buzzer
9) Visual marker attachment
10) Battery connectors
11) 9V Rechargeable batteries
12) Continuous-rotation servos
13) 3D-printed robot wheels
14) Rubber outer-wheel rings
15) 3D-printed GNBot chassis
16) Marble for the idler wheel

Fig 3: Parts that form one GNBot. Total cost ~150€

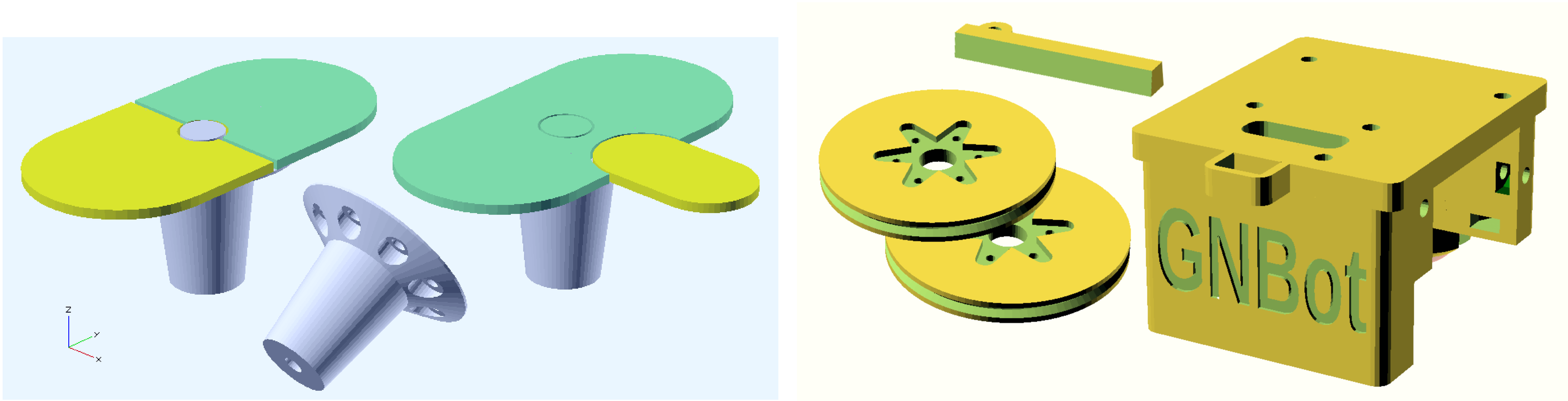


Fig 4: The GNBot parts are designed to be 3D printed, which reduces costs and allows repeatibility for the creation of large robot swarms

Efficient communication strategy based on ZigBee

The robots can be configured to stream all sensor data in real time, at a sample rate Ts that can be modified live. A central computer processes the information and returns commands to each robot, in order to determine their behavior.

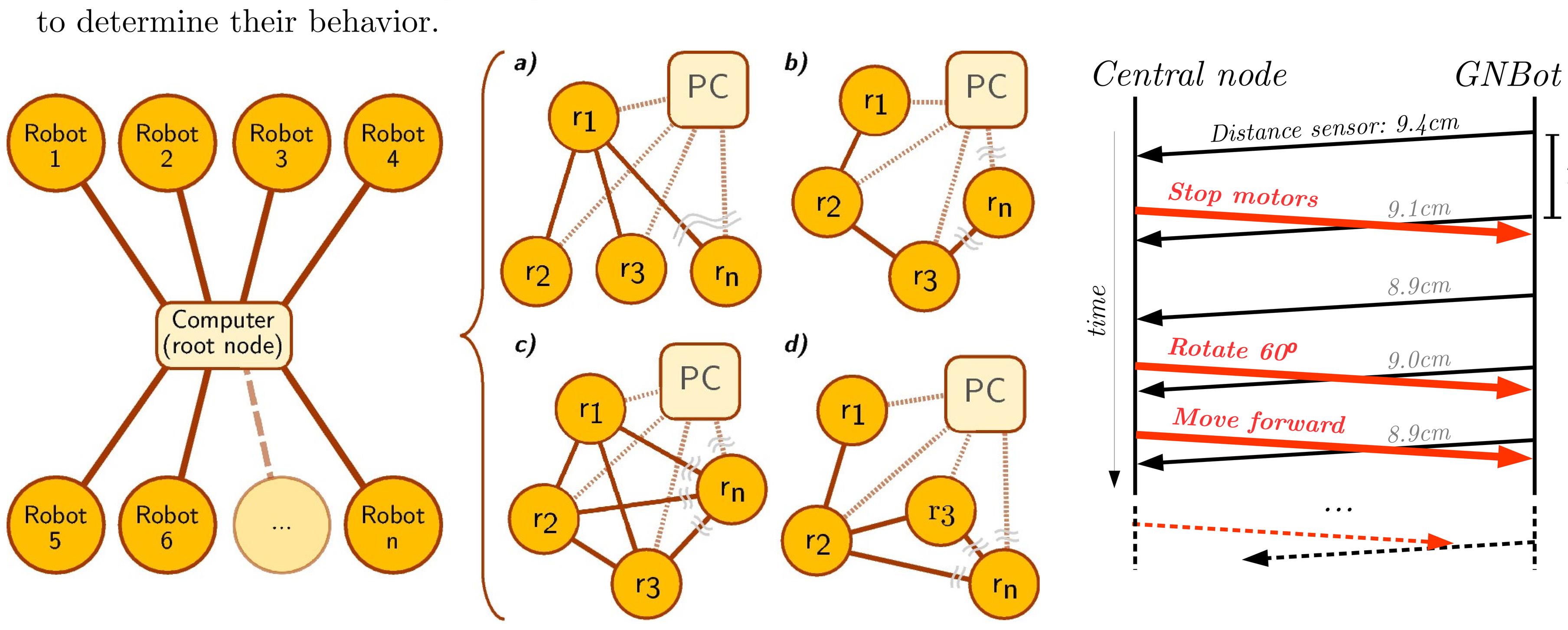
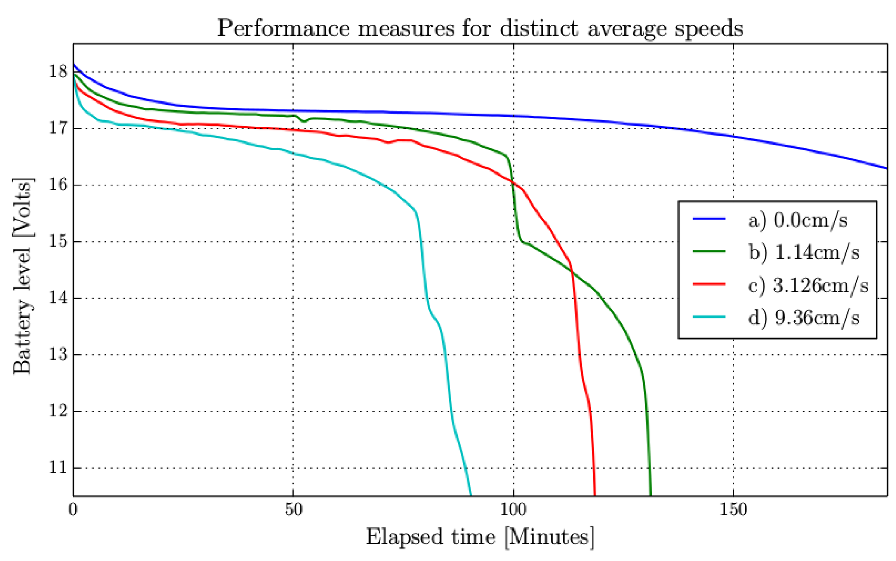


Fig 5: Centralized communication strategy that simplifies the evaluation of many different architectures and allows real-time logging

3. Performance of the GNBot platform



The knowledge of various differentiated stages on the battery life is useful information that can be incorporated to trigger a decision-making event during search, to optimize the use of energy resources. For example, abrupt changes on battery level can trigger a speed change, shutting down high consumption sensors such as the electronic nose, or altering the decision of which robot approaches a given target (cf. Fig. 2).

Fig 6: Battery level measurements. *Operating time: a) 255min b) 131min c) 119min d) 91min. Distance range estimation: a) 0m b) 90.29m c) 222.26m d) 505.44m*

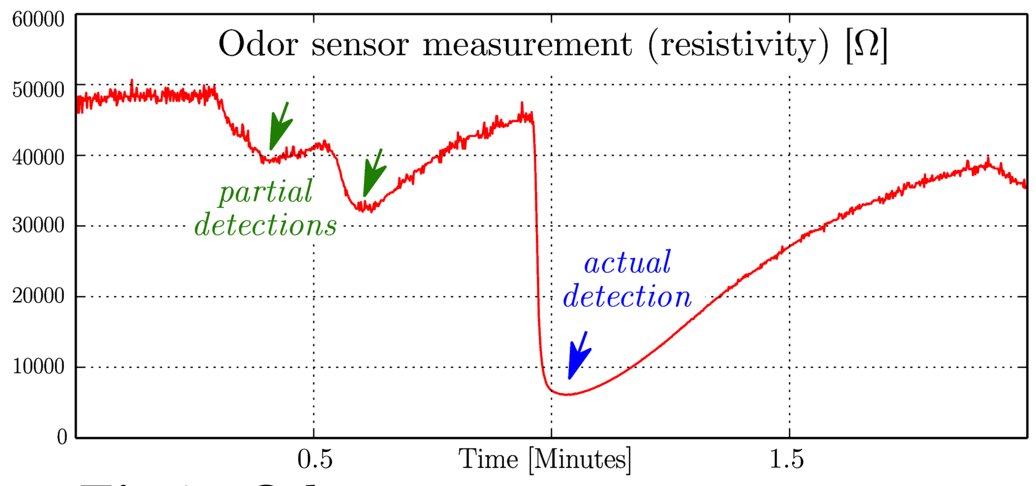


Fig 7: Odor sensor measurements

The TGS-2600 gas sensor is modeled as a resistor whose value varies in relation with the perceived odor intensity. A reduction of resistance indicates the detection of a significative amount of odorant molecules in air. That way it is possible to identify the presence of an odor source as a falling edge in the resistance of the odor sensor.

Robot position tracking with visual markers

The position of the GNBot can be tracked with computer-vision algorithms. Perspective correction and color thresholds have been used to detect the position and orientation of the markers on board each robot, which can serve for closed-loop motion control.

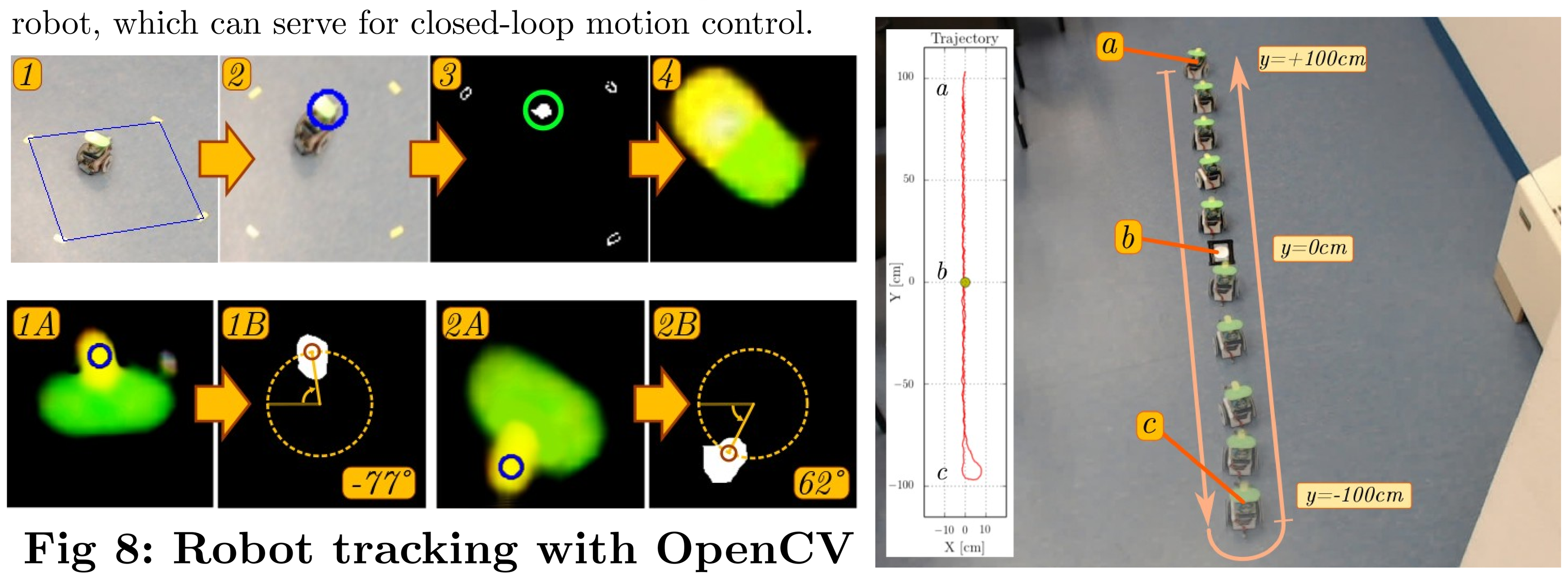
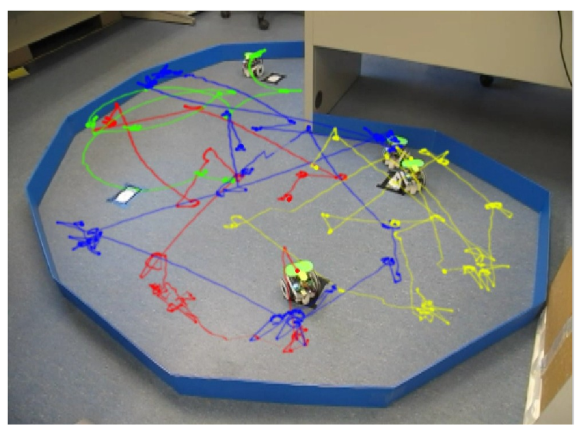


Fig 8: Robot tracking with OpenCV and closed-loop positioning

4. Validation with a bio-inspired *Lévy walk* search strategy



Cooperative odor localization video: http://youtu.be/HuAor0oZO_s

See our live demo tomorrow at the conference!

Fig 9: Lévy walks for multiple odor source localization

Conclusions

- A flexible open-source robotic platform, the GNBot, has been developed. It provides multi-sensor integration (including an artificial nose) and internal resource feedback via battery voltage monitoring.
- A software layer has also been developed to abstract the communications and facilitate the implementation of a wide range of searches.
- Finally, the GNBot has been validated with the implementation of a cooperative bio-inspired Lévy walk odor search strategy.

Acknowledgements

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