The Artificial Mouse - A Robot with Whiskers and Vision

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Abstract

In this paper we present the current implementation of the artificial mouse (AMouse), a robot based on a Khepera platform with two active artificial whisker arrays and an omnidirectional camera. This robot has been designed in close cooperation with biologists and neuroscientists to serve as a tool for studying biological models of rodent behavior. Furthermore, the interplay between different sensory modalities - visual and somatosensory - can be investigated. An important somatosensory organ are whiskers. Whiskers are versatile sensors for short-range navigation and exploration that are widespread in many animal species, especially in rodents. Rats for example can use them for local navigation, for exploration of objects (3) and for discrimination of different surface textures (6).

The artificial whisker sensors we use consist of capacitor microphones with natural whiskers attached to them (14). Physical force on the whisker hair deforms the microphone membrane and results in a voltage signal different from the resting state. This signal from the microphone is amplified on the robot and sampled on an external computer.

A prerequisite for the rat's survival in a complex environment is the ability to navigate, searching for food and finding back to its home position. Rats are able to apply a variety of different navigational strategies such as aiming towards a salient beacon, guidance, or even complex strategies using a mental image of its environment. The discovery of place cells in the rat's hippocampus in the early 1970s gave insight into the underlying neural representation. The firing rate of these place cells correlates with the spatial position of the animal. Simulated place cells are used on a mobile robot that learns to navigate within its environment through exploration tours. The place cell model is enhanced with local navigation skills based on the snapshot hypothesis (5). The major sensory information is gained from a camera providing the robot with omnidirectional vision, similar to the large visual field of rats and mice. We are currently investigating how tactile information from the whisker array on the robot can be used as an additional sensory modality for biologically inspired navigation.

1. Introduction

Rodents and many other animals use whiskers for exploration of close objects, and for navigating in complex environments and darkness (20). As many of them are nocturnal animals, they have to be able to gather other sensory information than vision. With their whiskers, they are able to discriminate textures of different roughness by actively whisking the surfaces (6) (10). Furthermore, animals use whiskers extensively as distance and collision sensors. Fast and easy evaluation of distances to objects is crucial when moving at high speed, e.g. when fleeing from predators or when hunting. Such evaluation of sensory information can be greatly facilitated by an appropriate morphology of the sensor distribution.

While other sensory modalities such as vision already provide a lot of information that can be analyzed statically, a tactile sensor usually needs to gather information over time. This can be done either in an active way by moving the sensor over a surface (19), or passively, when the object is moved over the sensor. The necessity for active sensing can easily be made plausible: With a fingertip placed lightly on a surface without any movement across, it is very difficult to discriminate different textures. The task becomes fairly easy for us, when we start to move the finger across the surface. This example shows how tactile exploration can be facilitated by active movement. In fact, rats and mice move their whiskers actively back and forth (22) with about 8 Hz when exploring objects (6). As they whisk, their whiskers move synchronously most of the time (17). For this reason one of the important features of the whisker system studied in AMouse is the use of active whisking for various tasks.

Despite their enormous potential as close-distance touch sensors that do not involve heavy contact with objects (23) (21) and that are independent of light, whiskers have not received a lot of attention from roboticists. Mainly, whiskers have been used as binary touch (24) or as strain sensors (13) and it has been shown within an engineering approach (12) that they can be used for fast obstacle avoidance on a robot. Some experiments have already been conducted with previous versions of the artificial whisker system described in this paper. Lungarella et al. (14) have studied the influence of the whisker material on the signal transduction properties. They found that in fact the natural rat whiskers had the most diverse frequency spectra when moved over different textures. The study of texture discrimination was further elaborated using an active whisker array in (7), while the influence of morphology of the whiskers in relation to the robot body was studied on an obstacle avoidance task in (8).

Figure 1: Picture of the AMouse with its whiskers and the omnidirectional camera.

Useful as they are for short range navigation, whiskers have a very narrow range for exploration: in most cases, anything they do not touch, they do not perceive. Thus for long- or mid-range exploration and navigation, vision is an important sensory modality.

A large amount of biological research has been devoted to navigation strategies of rats, and in particular to the role hippocampal place cells (16) play for this task. Place cells are pyramidal cells found in the hippocampi of rats and mice, which firing rate correlates with the animal being at a certain position within its environment. In a newly explored environment, place cells usually appear after a few minutes of exploration. The main sensory modality used for the creation and recall of place cells is vision, however, tactile and auditory information also play an important role (18). The use of place cells facilitates way finding strategies of rats which are used in addition to local navigation strategies such as search, aiming or guidance. Several navigation strategies implemented on mobile robots are inspired by rat's place cells (11) (1)(9). The robots all rely on omnidirectional vision and a compass.

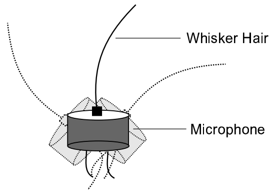


Figure 2: Scheme of the movement of the whisker on the microphone, when tilted at the base. In light gray, the end positions of the whisker sensor can be seen.

2. The Artificial Whisker System on the Mobile Robot

2.1 *The Artificial Whisker System*

The Artificial Mouse Project aims a modelling the mouse and rat whisker system with focus on the interplay of the whisker system with the visual modality. A synthetic model has to keep the balance between mimicking the biological model, the whisker pad of rodents and the technical abstraction, the artificial whisker sensor and the active artificial whisker array. Abstractions from the biological reality have to be done on several levels.

2.1.1 *The artificial whisker sensor*

First we had to decide on the sensor itself. While rats and mice have multiple receptors around the whisker hair, we have chosen a one-dimensional sensor, namely the capacitor microphone already described (14) (see figure 2). While the microphone sensor has a good signal-to-noise ratio and is able to follow high-frequency movements of the whisker hair (for an example of the sensor signals see figure 3), it cannot transmit any information about the deflection direction of the whisker. This shortcoming was accepted in order to keep the synthetic model as simple as possible.

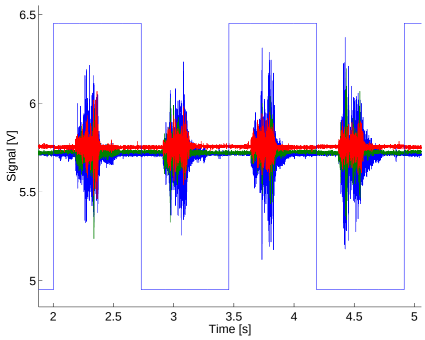


Figure 3: Example of raw data from several whiskers when actively whisking a surface.

2.1.2 *Actively moving the whiskers*

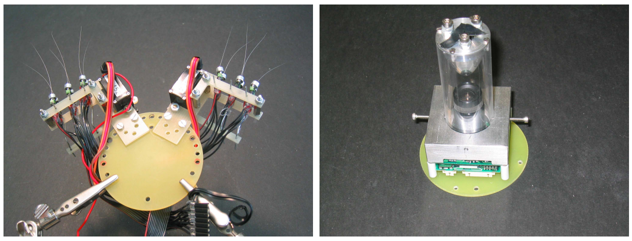
Having chosen a sensor, the design of the active whisker array had to be determined. Rats can move their whiskers separately in two dimensions, but mostly they move them in synchrony and in a more or less forward/backward sweep. Since it would have been very complicated and space-consuming to give each whisker two degrees of freedom, our whisker array moves all whiskers synchronously in one dimension, which also facilitates motor control and the integration of motor feedback with the sensory signals.

The movement pattern of the natural whiskers is a wide sweep of the tip accomplished by a small tilt of the whisker follicle. We have strived for a similar motion by tilting the microphone base of the whisker sensor. The angular movement achieved by our device was about 80°. The artificial whisker array consists of six whiskers arranged in two rows (figures 4(a) and 4(b)).

In order to enable easy and fast exchange of sensors within the array, the sensor is fixed on small plugs. Thus the material of the whisker, its length and orientation can easily be changed for the study of the role of morphology for signal processing and behavior.

2.2 *The Robot Architecture*

For some of our experiments we use natural rat whiskers. In order to roughly preserve the relation of body size and whisker length, we have chosen a small commercial robot platform, the Khepera robot by K-Team (15). The Khepera is a cylindrical robot with a diameter of 6 cm, 2 motors, 8 light sensors and 8 infra-red sensors that can approximate touch sensors on the robot body. The size constraints on the robot posed some challenges on the construction part, because we had to fit the whisker arrays, the servo motors, the amplifier board and the camera on such a small robot. This problem was solved with a modular architecture, adding layers for each functionality to the robot. The first layer can be used to fix the two whisker arrays on the robot (figure 5(a)). These arrays can be fixed in different positions so experiments on the morphology of the whisker arrays on the robot can be conducted (8). An omnidirectional camera using a parabolic mirror constitutes the top layer of the artificial mouse (figure 5(b)). An omnidirectional camera was chosen as it corresponds nicely to the wide field-of-view of mice and rats. Furthermore, we hope to be able to integrate navigational strategies developed at the Artificial Intelligence Lab in Zurich that are based on a similar camera system.



(a) (b)

Figure 5: (a) Picture of the layer containing the two whisker arrays. Multiple sites are prepared for fixing the whisker arrays to allow for different morphologies (b) Camera layer with the omnidirectional camera.

The final AMouse robot with the acoustic sensors can be seen in figure 1. Data acquisition and processing is done on a laptop computer to have a mobile setup for experiments at different sites and environments.

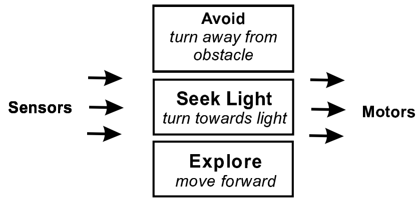
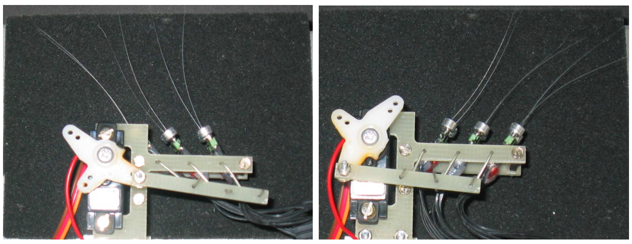


Figure 6: Schematic of the behavioral modules in the subsumption architecture. The modules are shown in descending order of priority.



(a) (b)

Figure 4: The active whisker array. (a) Left-most position of the whiskers. (b) Right-most position of the whiskers.

3. Behavioral Experiment: Phototaxis of the AMouse

For a first experiment using both tactile and a simplified visual signal, a light-seeking (phototaxis) behavior was implemented. The robot has eight ambient light sensors which can be interpreted as primitive visual input. The range of these light sensors is limited to about 20-30 cm depending on the light source. For local navigation the robot relies primarily on its whiskers: to avoid collisions it used its whiskers as distance sensors similar as described for Braitenberg vehicles (2) (see schematic of the network: figure 7).

3.1 *The Control Architecture*

The robot had a repertoire of three behaviors organized as a subsumption architecture (figure 6), (4): The simplest behavior is ”move forward”, the other two behaviors are ”seek light” and ”avoid obstacle”. To avoid damage to the robot through collisions, the obstacle avoidance module can suppress the two other behaviors if the whiskers are activated through touch. The light seeking behavior suppresses the “move forward” module when the light sensors detect a light source and take over the control over the wheel motors. The influence of the sensory signals on the wheel motor speeds is described in more detail in the following paragraph.

The ”seek light” behavior is active, if the robot detects light, but does not get any signal from the whiskers. It then drives towards this light source by modulating the speed of the wheels. If the strongest activation is at the rear of the robot, it simply turns by 180° and continues with the default behavior. Otherwise the focal point p of the activation on the remaining six sensors is computed:

$$p = \frac{1}{s_{mean} \cdot S_{front}} \sum_{n=1}^{S_{front}} s_n \cdot n \tag{1}$$

where S_{front} is the number of sensors s in the front of the robot and s_{mean} is the average activation of all sensors in the front of the robot. The angle α of the vector which points from the robot towards the light source can now be described as:

$$\alpha = (p - 3.5) \cdot 30 \tag{2}$$

The wheel motors are thus set to the following values in order to let the robot drive towards the light:

$$\text{motor}_{left} = \cos(\alpha + 45) \cdot 5 \tag{3}$$

and

$$\text{motor}_{right} = \sin(\alpha + 45) \cdot 5 \tag{4}$$

The addition of the 45 degrees rotates the robot (or rather the vector) in a way, that $m_{left} = m_{right}$ if the angle α is 0, causing the robot to drive straight forward. For the ”avoid obstacles” module, the motor speeds were taken from the network in figure 7 and applied for 0.1 s. This module had priority over both ”seek light” and ”move forward”.

3.2 *Light-Seeking Behavior*

We conducted a total of eight runs with different conditions. First we tested the influence of the light source on the success in light seeking and found that light from a white LED did not stimulate the light sensors strong enough (see figure 8). In this run, the robot trajectory was hardly influenced by the light source, even though to an external observer the robot was moving in bright light.

A more successful run was achieved with a halogen light source (figure 9). The light source was placed in one corner of the experimental area, while the robot started in another corner. Because in the beginning the robot was too far away from the light source to detect any signal it started with the default ”move forward” behavior. When it first detected light, it followed the direction of the strongest activation of its sensors. Due to mirrors within the light source the brightest light was not in the middle of the light cone, but along certain reflection lines. The robot followed these lines of highest intensity until it reached the corner of the light source. Since the robot

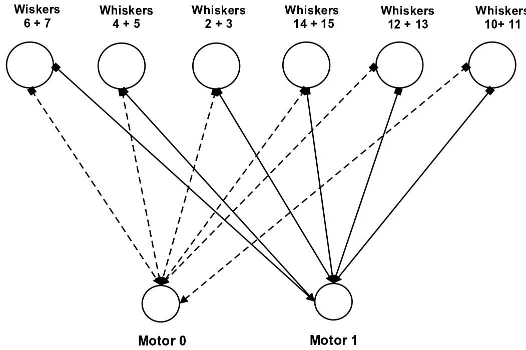


Figure 7: Schematic of the neural network connecting the whiskers to the motors. The weights were determined heuristically.

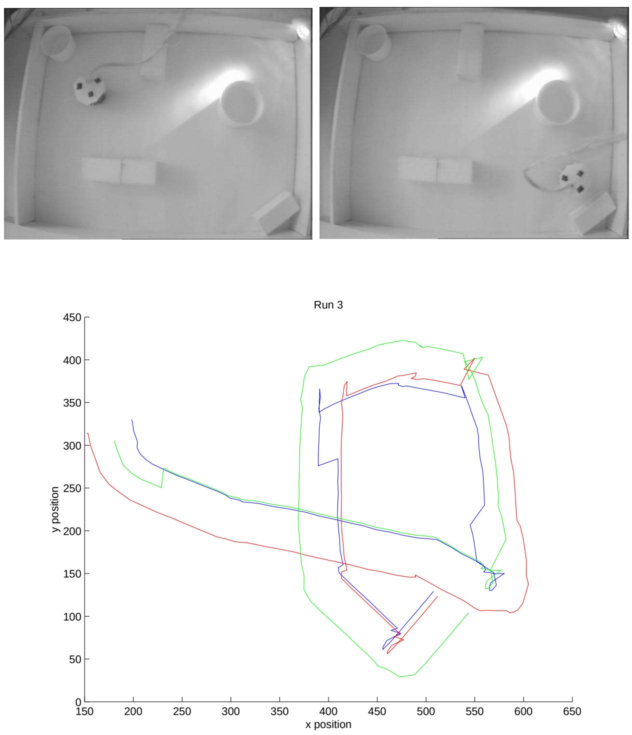


Figure 8: Testing an LED as light-source. (b) start position of the robot in the arena (c) end position of the robot during this run. (a) trajectory of the three labels on the robot

has no behavior to stop at a certain brightness, it continues to move and search even when it has reached the target. This might look as follows: once it reaches the wall where the light is very bright, it starts to avoid the wall, drives a little away from the light source, approaches, avoids again and so forth, until the experiment is stopped.

In a last run, the light source was moved to different positions during the run. The trajectory in figure 10 and the video show that it nicely followed the light into different areas of the experimental arena.

4. Discussion

Sensor-based navigation is an important issue in mobile robotics. For many mammals vision is one of the most important sensory modalities, especially for long range navigation. But for night-active animals like rats, bats or moles, vision is not as useful. Bats for example have a highly specialized auditory system for navigation and localization of prey. Rats use vision, olfaction and auditory cues for long-range orientation, but for local navigation, somatosensory information from the whiskers become very important. In the AMouse robot, we have demonstrated how basic vision and somatosensation based on whiskers can be combined for an aiming task. Since the light sensors had a range considerably larger than the whiskers they were needed for the long-distance navigation towards the light source. On the other hand, since there were still obstacles in the environment that could not be sensed by the light sensors, whiskers were crucial for the short range navigation especially in the case of dark corner. In such dark areas of the environment, the light sensors were not useful as they were not detecting anything.

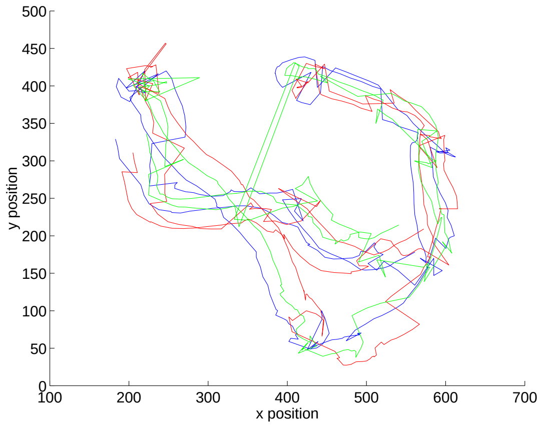


Figure 10: Trajectory of the AMouse with a moving light source. The robot follows the light to different areas of the arena.

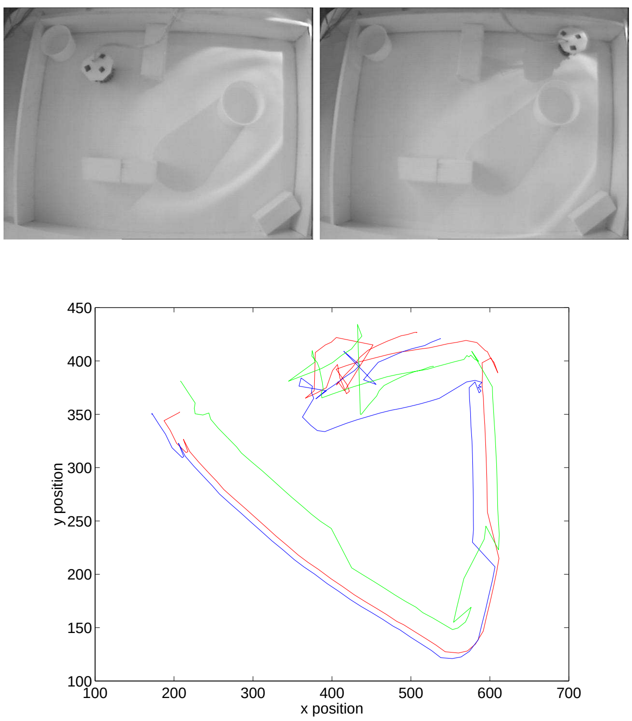


Figure 9: Testing a halogen light source. The robot follows along the bright light until it is nearly at the source. (b) start position of the robot in the arena (c) end position of the robot during this run. (a) trajectory of the three labels on the robot

While there was no learning involved so far, the robot is ready to be extended with more sophisticated forms of navigation based on vision such as place-cell inspired navigational models. Additionally it will be most interesting to investigate how the visual and the somatosensory modality can be combined for classification and navigational tasks. While visual input can be processed on a static image, the whisker data is always temporal. Without change there is no sensor reading. It is also independent of lighting conditions while a camera fails once it gets dark. We expect that for stable navigation it will be useful to combine the tactile and the visual modality to be able to produce coherent behavior, even if one of the senses encounters unfavorable conditions, such as darkness.

5. Conclusion and Future Work

In this paper, we described how obstacle avoidance can be combined with phototaxis, an aiming behavior. Aiming behavior falls into the category of local navigation behaviors, such as search and guidance. We are interested in implementing other local navigation strategies by combining whiskers and vision. A further step is the implementation of way-finding behavior, more precisely place cell inspired navigation methods, which are very well studied in rats. Place cell navigation often requires local navigation strategies as building blocks to result in meaningful behavior. We want to combine visual information and tactile information on textures and shapes gathered by the whiskers for learning of places cells and other tasks. We will investigate how the differences in the sensor modalities affect behavior and learning, and how redundancy can be exploited when the conditions for one of the modalities become unfavorable.

Acknowledgements

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References

A. Arleo and W. Gerstner. Spatial Cognition and Neuro-Mimetic Navigation: A Model of Hippocampal Place Cell Activity. *Biological Cybernetics*, 83:287–299, 2000.

V. Braitenberg. *Vehicles. Experiments in synthetic psychology*. MIT Press, Cambridge, 1984.

M. Brecht, B. Preilowski, and M.M. Merzenich. Functional architecture of the mystacial vibrissae. *Behavioral Brain Research*, 84(1-2):81–97, 1997.

R.A. Brooks. Intelligence without representation. Number 47 in Artificial Intelligence, pages 139–159. 1991.

B.A. Cartwright and T.S. Collett. Landmark Maps for Honeybees. *Biological Cybernetics*, 57:85–93, 1987.

G.E. Carvell and D.J. Simons. Biometric analyses of vibrissal tactile discrimination in the rat. *Journal of Neuroscience*, 10(8):2638–2648, 1990.

M. Fend, S. Bovet, H. Yokoi, and R. Pfeifer. An active artificial whisker array for texture discrimination. In *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2003.

M. Fend, H. Yokoi, and R. Pfeifer. Optimal morphology of a biologically-inspired whisker array on an obstacle-avoiding robot. In W. Banzhaf, T. Christaller, P. Dittrich, J. T. Kim, and J. Ziegler, editors, *Advances in Artificial Life - Proceedings of the 7th European Conference on Artificial Life (ECAL)*, volume 2801 of *Lecture Notes in Artificial Intelligence*. Springer Verlag Berlin, Heidelberg, 2003. in print.

D. Filliat and J.A. Meyer. Global localization and topological map-learning for robot navigation. *Proceedings of the 7th international conference on simulation of adaptive behavior (SAB)*, 7:131–140, 2002.

E. Guic-Robles, C. Valdivieso, and G. Guajardo. Rats can learn a roughness discrimination using only their vibrissal system. *Behavioural Brain Research*, 31(3):285–289, 1989.

V.V. Hafner. Learning Places in Newly Explored Environments. *From Animals to Animats. SAB2000 Proceedings Supplement Book*, pages 111–120, 2000.

D. Jung and A. Zelinsky. Whisker-based mobile robot navigation. *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2:497–504, 1996.

M. Kaneko, N. Kanayama, and T. Tsuji. Active antenna for contact sensing. *IEEE Transactions on robotics and automation*, 14(2):278–291, 1998.

M. Lungarella, V.V. Hafner, R. Pfeifer, and H. Yokoi. An artificial whisker sensor for robotics. *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pages 2931–2936, 2002.

F. Mondada, E. Franzi, and P. Ienne. Mobile robot miniaturisation: A tool for investigation in control algorithms. *Proceedings of the Third International Symposium on Experimental Robotics*, pages 501–513, 1993.

J. O'Keefe and L. Nadel. *The hippocampus as a cognitive map*. Oxford University Press, 1978.

R.N.S Sachdev, S. Takashi, and F.F. Ebner. Divergent movement of adjacent whiskers. *Journal of Neurophysiology*, 87:1440–1448, 2002.

E. Save, L. Nerad, and B. Poucet. Contribution of Multiple Sensory Information to Place Field Stability in Hippocampal Place Cells. *Hippocampus*, 10:64–76, 2000.

M. Shimojo and M. Ishikaw. An active touch sensing method using a spatial filtering tactile sensor. *Proc. IEEE Int. Conf. Robotics and Automation*, pages 948–954, 1993.

S.B. Vincent. The function of the vibrissae in the behavior of the white rat. *Behav Monographs*, 1(5), 1912.

S.S.M. Wang and P. Will. Sensors for computer controlled mechanical assembly. *The industrial robot*, March:9–18, 1978.

W.I. Welker. Analysis of sniffing of the albino rat. *Behavior*, 22:223–244, 1964.

P. Will and D.D. Grossman. An experimental system for computer controlled mechanical assembly. *IEEE Transactions on computers*, c-24(9):879–888, 1975.

U. Zimmer. Self–localization in dynamic environments. *IEEE/SOFT International Workshop BIES'95, Tokyo, Japan, May 30-31 1995.*, 1995.