THE CONCEPT OF ROBOT SOCIETY AND ITS UTILIZATION

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ABSTRACT

Societies are formed as collaborative structures to execute tasks which are not possible or are difficult for individuals alone. There are many type of biological societies, but societies formed by machines or robots are still rare. The concept offers, however, interesting possibilities especially in applications where a long term fully autonomous operation is needed and/or the work to be done can be executed in a parallel way by a group of individuals. The paper introduces the basic control and communication structures of robot societies by using a model society. Also a mini-scaled mobile robot which is under construction to be multiplied for the corresponding physical society demonstrator is introduced. Simulation results illustrating the behaviour of the model society are given. Possible applications in waste treatment and process monitoring and cleaning are considered.

1. INTRODUCTION

Societies are formed as collaborative structures to execute tasks which are not possible or are difficult for individuals alone. In some cases societies can be seen also as alternatives to large size more complex individuals. There are many type of biological societies formed by animals and by humans. Societies formed by machines or robots are still rare. The related research activity is, however, quite lively today, if we consider such topics like different kind of multirobot environments, autonomous agents and artificial life (see e.g. [1] - [4]).

There are at least two basic reasons why the concept of robot society is of potential interest as engineering solutions. The first reason is fault tolerance. A machine society has a high redundancy, because in a society concept the functions of a faulty individual can be always easily replaced by other members. The second reason is the member to member communication structure which makes it possible to increase or decrease the number of the members in a society easily without any reconfiguration of the communication structure. Applications where a long term fully autonomous operation is needed and/or the work to be done can be executed in a parallel way by a group of individual robots are natural tasks for robot societies.

The concept of robot society is potential in many applications related to environment protection, because related tasks have to be done often in unbenign and unstructured work environments where traditional robotics encounters problems. A couple of such scenarios are described later on.

The paper introduces the basic control and communication concepts of a robot society based on the research done in our laboratory. The concepts are illustrated by a model society which is formed by mobile robots which search and collect stones in a limited but initially unknown area. The society have two type of members: work units which collect the stones and support units which carry energy resources and act as work coordinators. The work units have a limited energy resource which is refilled from the support units (called also energy units). Thus the society can also distribute energy like it distributes information. To illustrate the properties of the model society we have made a computer simulator and to concretize the idea we are also presently constructing a physical society which consists of mini-scaled mobile robots. Both are shortly described and some basic behavioural properties of the society discussed.

2. THE CONCEPT OF ROBOT SOCIETY

Basically every society is a group of individuals, which we called members, with an information and a control structures. All members of a society need not to be similar. Members having same properties can form clusters or classes. The information structure defines how information is spread within the members and how an individual member communicates with the other members of the society. The control structure defines the way how the society affects to its members. Because all working power is produced by the members the control structure controls the task execution of the society. Because both structures in human societies are very complex, we are not trying to analyze or imitate them when modelling the robot societies. Anyway, robot societies are artificial ones and we can define exactly the both structures. At the first we may also assume that these structures are constant and the society cannot redefine them as happens quite often in human societies. More suitable model societies can be found rather by considering the societies formed by lower level animals like insects, e.g. ants or bees [5], [6]. It should be observed, however, that the society structure which we are looking for is more than just a group or herd of animals without no clear information or control structures.

The ultimate practical goal of the robot society concept is to construct a kind of "distributed robot" or "group robot" which can execute tasks which are defined by the user or "society controller", like in the case of a conventional individual robot. This means that the behaviour of the society must be controllable outside and that the society must thus have information connection to the controller. However, it is important from practical point of view that this connection is not built to every member of the society, but rather to the information system of it. This is because a society may include a large number of members which are located in places where a communication system is difficult to build. Basically the communication in a society is done on member to member bases.

Although the concept of a society doesn't limit the size of the members anyhow, it is quite natural to think that members are small sizes. In a very small scale, i.e. the scale of micro-machinery, the society concept is a very natural one to be utilized. One can see the same in the biology, too. Many small size animals are represented in groups (not all are forming societies in the sense we are talking about!) and so they have in a sense divided one body to many pieces. In spite of a small size of an individual and consequently a limited capacity of it, a large number of individuals can execute amazing jobs.

One of the very attractive property of a society is that its functioning is not dependent on one individual. The functions of an individual can be always replaced completely by others and this does not need any reconfiguration of the society. Thus the redundancy of the system is high. The other interesting property which might be utilized in some applications is information structure which is based on member to member communication. This have the advantage that the communication system is very flexible and the capacity is not limited by the number of members. Also new members can be easily added to the society at any time.

Biological societies like ant or bee societies have been formed trough evolution process during millions of years. It is therefore sensible to study the properties of these societies to obtain some reference models. The basic tasks done by both societies are to collect food, construct nest and protect own society. Analogy to these tasks may be found in technical applications also.

3. A MODEL SOCIETY

The robot society concept is illustrated here with a model society which is formed by mobile robots searching and collecting stones in a limited but initially unknown area. The stones are picked up and carried to a base station. The base station serves also as the interface with the user. The operator can send commands through it and information (like map information) collected by the members can be communicated further to the user. The robots are assumed to be able to avoid obstacles and each others (in a simple reactive way), and they can navigate by a simple dead-reckoning type of navigation system. Communication between the members can take place only locally by using the broadcasting principle so that only members within a certain maximum distance can hear what a talking member is saying. The talking robot reserves the space within the communication distance and forces the members inside it to listen. A set of simple messages can be sent and received to communicate following type of messages: coordinates of location, stones found, need help, detecting nearby units, change operation mode. The society has two type of members: working units which collect the stones and energy units which carry energy from the base station and act as work coordinators. The workers have a limited energy resource which is refilled from the energy units. Two members can also equalize their energy resources when meeting. Thus the society can also distributed energy like it distributes information. We have made a simulator for the model society and are also presently constructing a physical society from mini-scaled mobile robots.

The above society can serve as a simple model for example following tasks:

- mapping an unknown environment
- separating valuable or dangerous material
- finding and destroying specified objects in the environment

Depending on the detailed definition of the communication and control structures the society can behave in many different ways. We illustrate some properties by a simulation model in the next chapter. Because a physical realization always brings some additional details we are also presently constructing a mini-robot society to study and demonstrate real operations. The work unit robot is explained in more detailed.

4. SIMULATED BEHAVIOUR

4.1 Computer simulation

The computer simulator has been constructed to illustrate the basic properties of the simplified model society. Comparable simulations have been introduced among others by Mataric[7] and Hara[8]. It models a 2D environment which includes obstacles, stones, one base station and energy units illustrated in the Fig. 1. The environment is a (1000 X 1000) area illustrated in the Fig. 2.

The algorithms of the working units execute following tasks: random searching, moving towards a given destination and obstacle avoidance. The working units can communicate with each other, with the base and with the energy units. Possible messages include for example finding out the status of another member(position, energy level, etc.), getting information from the base concerning the operational mode and so on. The communication range is an adjustable parameter. In the following simulations the communication is related to energy behaviour. The obstacle avoidance is done in a reactive way by using five sensors (like ultrasonic) that cover 180 degrees in the front of the robot. The range of the sensors are 40 for point type of obstacles (stones or other members) and 25 for line type of obstacles (walls of bigger obstacles). The robots move with the step size of 20. When the energy level of a working unit drops under a specified minimum level it can navigate to the nearest energy unit for refilling supposing this can happen before its energy is completely finished. If a working unit loses completely its energy it dies. The energy units can hear the working units within the communication distance, they can move to a member which have used its energy, and they can cruise in the environment by avoiding obstacles and other units.

The simulator has been realized in a 486 PC by using MS-Windows programming environment and ACTOR object oriented programming language.

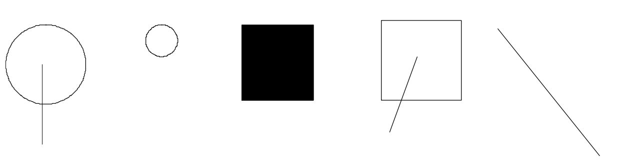

Figure 1. The parts of the environment as they look in the simulator are from the left; working unit, stone, base station, energy unit, line obstacle (walls of large obstacles). The line on the working unit and energy unit shows the direction of the member.

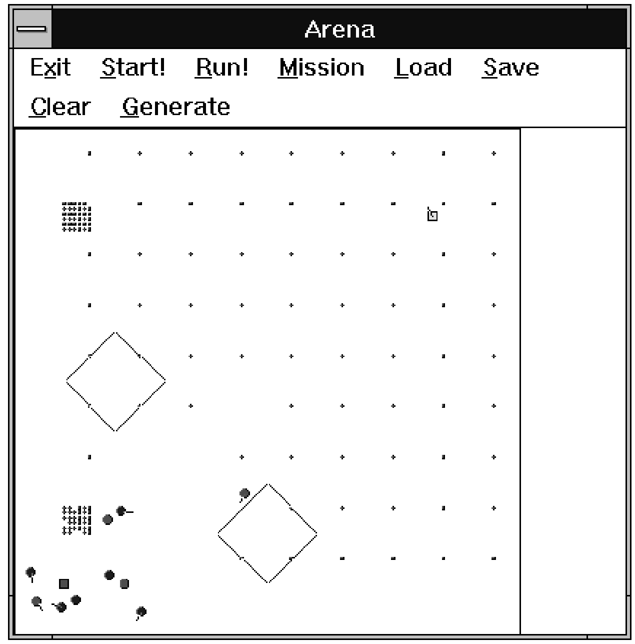

Figure 2: The simulation area during the simulation

The behaviour of the society and its efficiency when executing the collection task with different parameters can be studied by running the simulator. All simulations last 5000 time steps but if all 225 stones are collected before that or all working units are dead the simulation is stopped. Energy distribution, communication and the effect of the number of members are illustrated in the following. The data shown in Fig.3- Fig.9 is collected at every point by averaging results from several (2-5) simulation runs.

4.1.1 Energy distribution

The energy threshold is the energy level which causes a working unit to cancel working and to start move to the nearest energy unit for refilling. The energy threshold can be anything between 0-1000 and after recharging the energy level will be 1000. One interesting feature which can be found e.g. in ant societies is energy equalizing. This means that two members when they meet can equalize their energy storage. The interesting result, shown in Fig. 3, is that the energy equalizing property clearly helps to distribute the energy more efficiently which results a smaller number of dead members especially when a low energy threshold value (<300) is used. The energy per collected stones, however, increases, the number of stones collected during the simulation being about the same in both cases as illustrated in Fig.4. In these simulations the energy unit does not move and the working units can communicate all over the area.

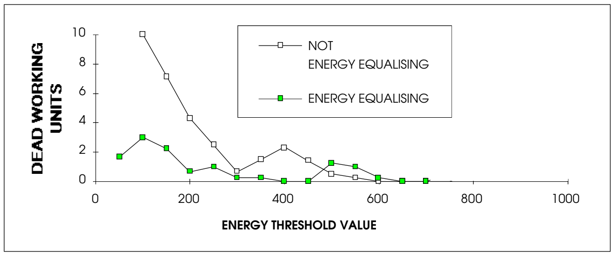

Figure 3: Using energy equalising the working units will not run out of energy as easy as they do while not using equalising. The difference is seen best at energy threshold values smaller than 300.

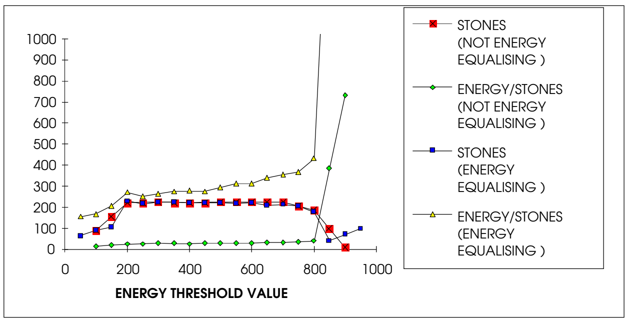

Figure 4: The energy used for collecting stones is bigger when using energy equalising than without it but the amount of collected stones is about the same.

4.1.2 Effect of communication distance

The effect of the communication distance is illustrated in the Figs. 5-7. An interesting observation is that the energy equalizing property looses its meaning when the communication distance increases. When a small distance (<200) is used almost all working units without energy equalizing property dies during the simulation. The energy unit is moving and the energy threshold used is 200 which according to earlier simulations sometimes leads to agents running out of energy.

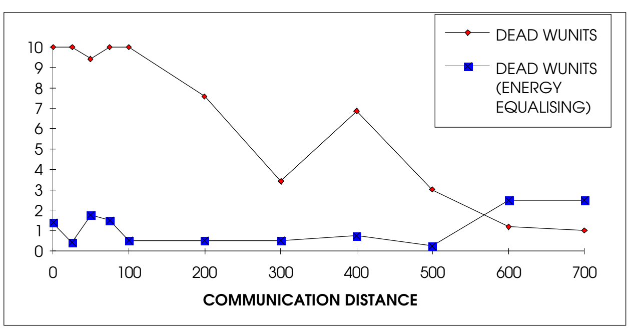

Figure 5: For communication distances less than 200 almost all working units without energy equalising dies during the simulation but working units with it will not die.

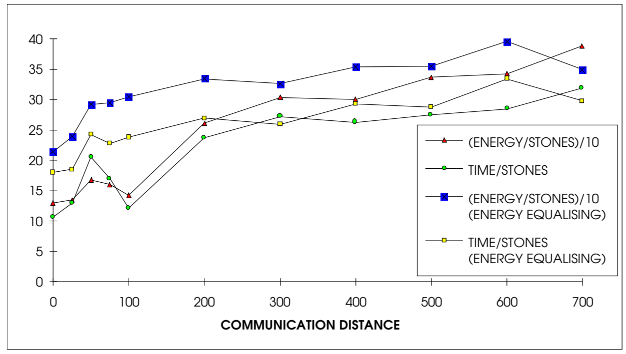

Figure 6: At bigger communication distances there is not a big difference between using energy equalising or not.

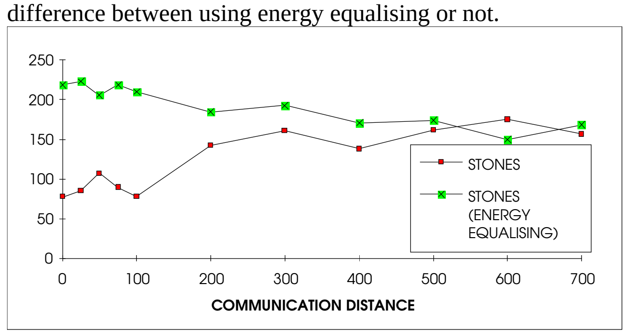

Figure 7: At small communication distances using energy equalising most of the time is used for collecting stones since energy is all the time available. If energy equalising is not used the time is used for searching for energy and thus they are not able to collect so many stones.

4.1.3 Number of members

The number of members has also some interesting features. As illustrated in the Figs. 8 - 9, the time and energy needed for collect a stone is strongly dependent on the amount of working units. There is also a minimum amount of agents needed for fulfilling the task. The communication area covers the whole simulation environment. The amount of energy units does not influence much, probably because in these simulations the area used is easily covered by one energy unit. The energy units are moving and the energy threshold used is 200.

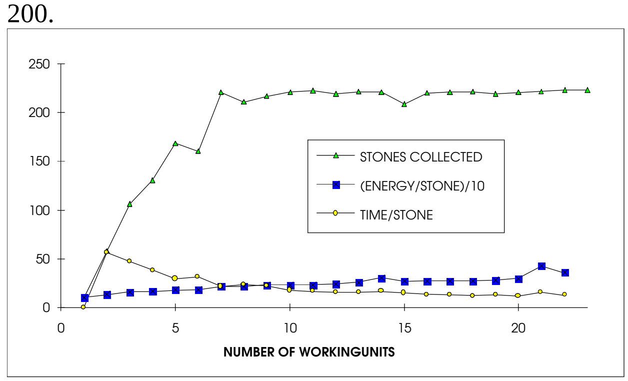

Figure 8: When using more members the time needed for collecting a stone is decreasing but the energy used per stone is increasing.

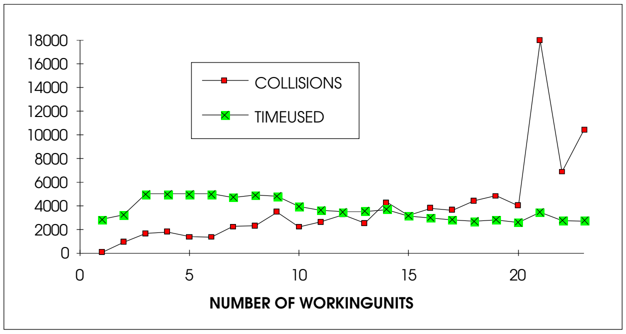

Figure 9. Using more members the time needed for the task is decreasing and the amount of collisions is increasing. The peek at 21 working units most likely corresponds to deadlock situation.

4.2 A physical realization

HUTMAN (**H**elsinki **U**niversity of **T**echnology's **M**obile **A**utonomous **N**avigator) was designed and built to provide a test-bench for developing a suitable structure for the model society member. Figure 10 shows a simplified picture of the robot with the basic processes listed.

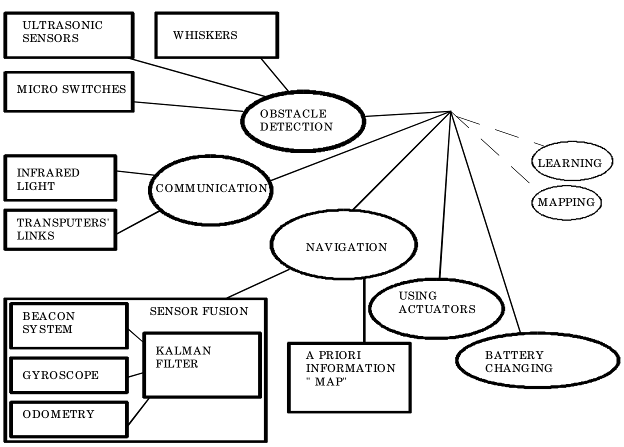

Figure 10: Basic processes in a robot society member

4.2.1 Construction

Due to the need to use several mobile robots in an office environment the size of the robot is quite small: the diameter of this turtle -type robot is 15 cm and the height is 14 cm. The total weight is less than 1 kg. It has two driven wheels and four balancing swivel castors. The robot uses two narrow beam ultrasonic sensors for obstacle and stone detection and it has two whiskers to give tactile information from the environment. Its navigation system is dynamic, using a modified Kalman filter to fuse the information from separate systems. To give HUTMAN the ability to fulfil the stone collecting task, a simple one degree of freedom gripper was designed for it. The robot is completely autonomous, it carries batteries with and the processing takes place only in processors located onboard. A more detailed description of the robot can be found from [9]. Figure 11 shows HUTMAN in a working environment.

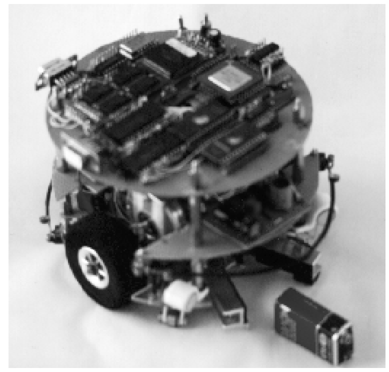

Figure 11: HUTMAN

4.2.2 Hardware

In an autonomous mobile robot the amount of data to be processed is very large. In our case the solution was to use transputers and their support for parallel processing. The physical structure of the transputer network is shown in figure 12.

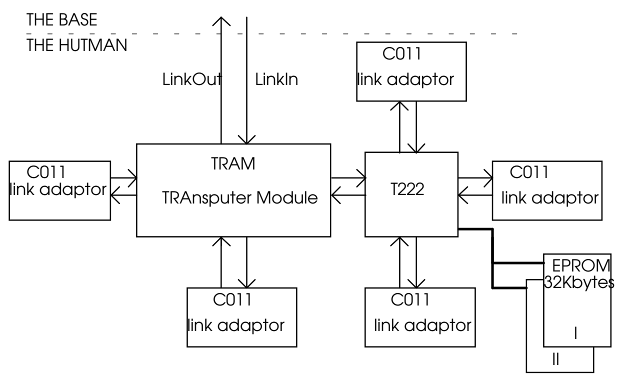

Figure 12: General hardware architecture

In this construction we use only two transputers, a Transputer Module(16 or 32 bits) and a T222 transputer(16 bits). The network is connected to the outer world via link adaptors, which are operating as interfaces between processors and sensors/actuators. All communication in the network is done through the transputers' standard links. Transputer based hardware solutions can be found e.g. from [10] and [11].

4.2.3 Communication

HUTMAN communicates using locally restricted randomly accessed broadcasting principle. The size of this local broadcasting space is adjustable and the actual communication is done with infrared light.

4.2.4 Navigation
The navigation system was designed to make the robot as autonomous as possible. The solution is a "hybrid" system. It is a combination of two different methods, a dead reckoning system with a miniature gyroscope and a beacon detection system (based on sound pulses and infrared light detection). The results from these two systems are combined using a Kalman filter to minimize cumulative errors. The general principles of this kind of system can be found from [12].

4.2.5 Software
The control structure of the robot and thus the foundation of the software is basically behaviour-based reactive control. The behaviour which the HUTMAN performs depends on three individual factors: the energy status, the communication, and the operational mode. The figure 13 illustrates these concepts. The triangle describes the robot and the three main factors are showed as crossing circles. The shadowed area where the circles interact, describes the actual working state of the robot.

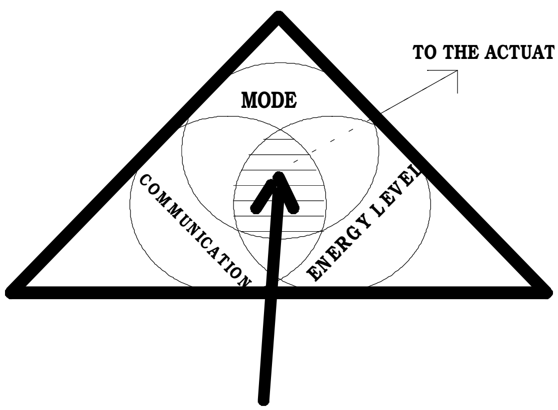

Figure 13: The control structure of HUTMAN

The actual code is physically divided into two separate blocks. The basic programs, which are essential for any kind of operation at all, are loaded to the EPROMs. The more sophisticated programs, which are not so vital, such as map building or travelled curve smoothing, are stored to the module's RAM.

4.2.6 Future developments
The development of HUTMAN is still going on. We are looking for smaller, lighter, more efficient, and less power consuming components. The idea is to take away everything that isn't necessary. Hopefully we will finally come up with a very small robot, which is clever enough but whose intelligence has been built up in the manner that when it starts to operate as a member of a robot society, the total intelligence of the society is much more than a plain sum of each individual robot's intelligence.

To reach this goal we are studying and testing several control structures, such as neural networks for controlling some restricted tasks or even to take care of a mobile robot's overall control as successfully done in [13]. Another topic which we are studying is to somehow move more intelligence down to the lowest level and thus get the sensors to process the data. After that the fusion of information would be much easier and the heavy and slow centralised control systems could be replaced by light and simple systems.

5. POSSIBLE APPLICATIONS

APPLICATION POSSIBILITY 1: DUMPING AREA MONITORING AND CLEANING

A possible practical scenario for the model society could be a dumping area society. Dumping areas are big problems as environmental risks because of harmful materials included. On the other hand they also include valuable materials e.g. metals which could be reused. Typically everything is mixed and the basic task is to find out and separate those materials from the other material. The robot society could include specially designed dumping area diggers who have sensors to detect dangerous and valuable materials, can collect them and/or make alarms. The energy carriers serve energy to the society as well as act as work leaders who also have connection to the operator station. The society is able to work 24 hours per day continuously and can produce a remarkable power in spite of one member is quite a slow and not so powerful machine. The work does not require high accuracy and is parallel in its nature. Technical solutions for mechanics, communication and control systems are not easy, but could be solved.

APPLICATION POSSIBILITY 2: MONITORING AND CLEANING INSIDE OF PROCESSES

In process industry, e.g. in paper industry, the use of natural water is becoming much regulated because of environmental reasons. Plants have to close their water circuits, which causes problems to maintain the water quality inside the process. Problems are caused e.g. contaminates coming from unfavourable bacterial growth. Cleaning can be done by chemicals, but because of a very big amounts of water it is very expensive and ineffective. What is needed is a kind of "precise weapon" which destroys the bacterial flocks (indeed the bacterial or algae growth often happens only some places) where they are met. A robot society which could do this job could include small "bacteria robots" moving along the process streams illustrated in the Fig. 14. They are equipped with biosensors to detect biological growth and two type of actuators. With the magnetic actuators they can fix to the process walls or to other individuals to form a more powerful flock, and with the enzyme actuator they can destroy the contaminates. The communication and control systems and the energy supplying system are nontrivial, but might be solved.

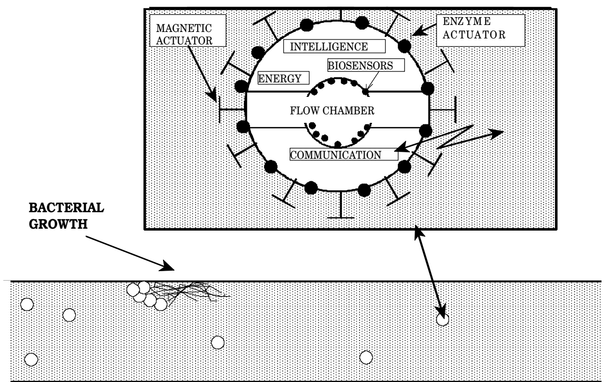

Figure 14: " The bacteria robot"

6. CONCLUSIONS AND FUTURE RESEARCH

The concept of robot society has been found interesting and potential in applications where the high redundancy, parallel working capability, simple structure and motion control requirements in the individual member level can be utilized. A robot society might make it possible to construct highly independent really autonomous machine systems in unbenign environments. The society structure offers also an interesting possibility to distribute and gather information and energy by member to member method.

The information and control structure of a robot society even simple can make the whole system difficult to analyze by analytical methods. As illustrated in the paper a simulator is an efficient tool to analyze its behaviour experimentally. Physical demonstrators are also important to be built because some features in the society might be much dependent on technical solutions used. Theoretical considerations are, however, also important. This is especially the case when we like to develop control concepts for robot societies. Too little is known today in this respect and one of our future goal is to develop a unified theory for the purpose.

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