Town Robot
– Toward social interaction technologies of robot systems –

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Abstract

This paper proposes a new research approach, which we call *Social Robotics*, for developing robots which works in human societies. The robots needs three elements: robot itself, infrastructures which support robot behaviors, and human interfaces for communication between robots, humans and operators who maintain the robot systems. The research approach aims to develop robust systems with the three elements and develop *Town Robots* which move in streets and interact with humans. The concept and fundamental issues are discussed and a prototype of the town robot is shown.

1 Introduction

Recent progress of computer technologies provides various systems which support humans social ability of information procesing and communications. An intelligent autonomous robot is considered to be one of such supporting systems for humans. Looking back history of intelligent robots, the study started in SRI [Nilson, 1984] and important component technologies of robots have developed such as sensors, manipulation and controllers. Efforts of integrating those components to realize autonomous robots have been also made. Pourposes of sevral robors developed so far were to study navigation technology or definite tasks in real environment. Recently several research groups are tackling to develop humanoid robots [Brooks,] [Honda, 1997] and entertainment robots [Fujita, 1997]. Those research objectives are to develop autonomous robots. How to apply robots to human societies have not been considered in robotics researches.

This paper proposes a new research direction called *Social Robotics*, in which robots are considered to be social information systems. We call a robotic system based on this concept *Town Robots*. That is because the robots interacting with humans will be on streets in town.

Let us look at previous robotics researches again and examine their approaches. Navlab project at Carnegie Mellon University [Thorpe, 1986] have developed autonomous vehicles which contain laboratory and researchers. The projects were successful for visual outdoor navigation both in on-road and off-road environments. The project's main purpose was to develop vision algorithms and systems for mobile robot navigation. Dickmanns, et.al. [1] also developed an autonomous vehicle which can drive in highway environment. For this pourpose They developed special parallel computers capable of high speed visual processing to control the vehicle. They are followed by other projects of developement of automated highway systems([**?**; **?**; **?**]). Yuta, et.al have developed compact size autonomous robots which can navigate in indoor and recently in outdoor environment of pedestrian streets [Yuta, 1991]. Their pourpose is autonomous navigation of the robot and their criterion of robot's autonomy is how long the robot moved in distance. Chatila et.al. proposed and developed an open and modular architecture of autonomous robots [Chatila, 1991]. Brooks [Brooks, 1986] proposed and developed a robust architecture of behavior based robots called *Subsumption Architecture*. Arkin, et.al. also developed an architecture of behavior based robots called *Schema system* [Arkin, 1993].

While surveying these works, we can see that only autonomy of robots have been studied and discussed, and the autonomy in this case means mobile ability of a robot itself. However robots are not isolated entities from human society, but robot system can be considered as an infrastracture of the society.

dealt with infrastructures and human interfaces. As humans need roads, traffic signs and so on, robots also need infrastructures for behaving in a dynamically changing world. Further, as humans needs, a robot also needs helps from others (humans and robots). That is, the previous works lack view points of the infrastructures and their social aspects.

For developing robust robot systems, it is strongly required to consider about infrastructures and interactions with humans. The basic idea of our approach is to design the robotics systems without loosing important elements of robots which works in real worlds. The elements are robots themselves, infrastructures supporting the robot functions and human interfaces communicating with hu-

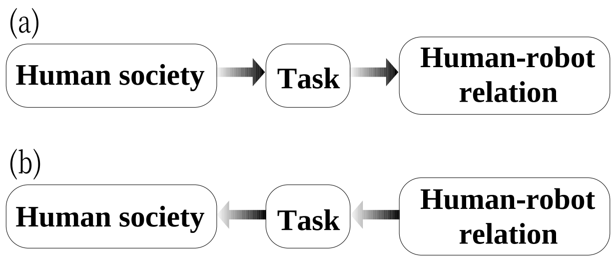

Figure 1: Human society and robot task

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2 Human society and robot task

Figure 1(a) indicates a previous research approach in robotics. Robot tasks are determined based on requirements from humans and human societies, and then robots are designed to complete tasks. The robots designed for the specific tasks have to work with limited human-robot interactions. For example, industrial robots which execute human tasks in factories have limited relations between humans and robots; robots do heavy labor and humans monitor robot behaviors.

However, we cannot determine tasks of robots behaving in open environment such as a town. The tasks should emerge from interactions between human and robot. Let us consider a robot capable of some high level functions such as carrying baggage, guiding humans, or communicating with humans. This robot may be used for pourposes which are not expected. When humans see this robot, they think what we want to do with the robot and what the robot can do, and ask various tasks to the robot. That is, the tasks are developed through human-robot interactions. Also the emerged usage of the robot may have influences on human societies. In other words, we can say that robots are used in human societies as a new information infrastructure. Figure 1(b) shows research direction of Town Robot. Tasks are found by humans while interacting with robots, then the human society is changed by the use of such emergent tasks.

We would like to mention one example of existing systems, which is the Internet. The research direction of Town Robot shown in Figure 1(b) have been also of the Internet. The Internet has been designed for just data transmission. However, it is important infrastructure of our society today and various application of the Internet are being developed. The web system is one of those applications. The web system influences and changes human societies. We consider robot system should be a similar system to the Internet.

So what is the robot tasks? We said that robot tasks can not be determined in advance. And also robot tasks will emerge from human robot interaction. Our answer for the question is as follows. The robot needs various relationships to be accepted in human societies. Tasks of the robot emerges only from the relationships with humans. Figure 2 shows the concept of tasks. In previous works, researchers tackled to develop robots for specified tasks. On the other hand, research approache of social robotics is to maintain the relationships and to encourage the task emergent.

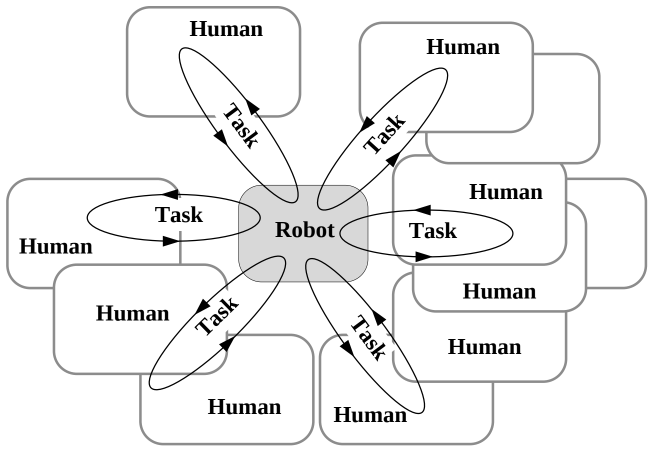

Figure 2: Relationships between a robot and humans

3 Technologies for interactions with human societies

The robot systems used in human societies need to satisfy the following requirements.

- *The system never halt*: For keeping interactions with humans, the system keeps on working even if the system sometimes locally halt.
- *The system emerges tasks*: The system should be flexible and open as humans can find tasks through interactions with it.
- *The system keeps on growing up*: The system should estimate relations with humans and develop new functions while working.

For realizing the functions memtioned above, three new technologies are necessary in addition to previous robot technologies. These technologies have never seriously discussed.

3.1 Infrastructure

To keep on working, robots need supports from the environment. With current technologies of autonomous robots, it is almost impossible to develop robust robot systems in real world which is complex and dynamically changing. The robots need a system which support their activities. *PI^2: Perceptual Information Infrastructure*, which we have proposed as an infrastructure of human society, is one of such sysytems [Ishiguro, 1997]. We have developed *Distributed Vision System* as a prototype of PII. Distributed Vision System consists of multiple vision agents connected through a computer network. The vision agents acquires visual information from various viewing points and provide various information of environment to the robots.

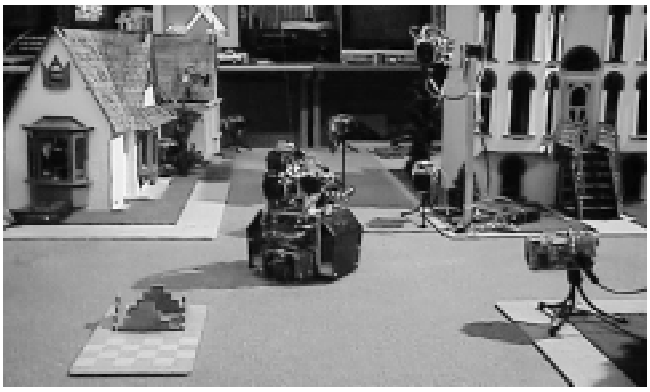

Figure 3: Distributed vision system for mobile robot navigation

In order to simultaneously execute the vision tasks, an autonomous robot needs to change its visual attention. The robot, generally, has a single vision sensor and a single body, therefore the robot needs to make complex plans to execute the vision tasks with the single vision sensor. *Active Vision* proposed by Ballard [Ballard, 1989] is a research direction to solve the complex planning problem with active camera motions bring proper visual information and to enable real-time and robust information processing. That is, the active vision system needs a flexible body to acquire the proper visual information like a human. However, the vision systems of previous autonomous robots were fixed on the mobile base and it is generally difficult to build autonomous robots which can acquire visual information from arbitrary viewing points in a 3D space.

Our approach to solve the problem is to use many vision agents embedded in the environment and connected them with a computer network (See Figure 3). Each vision agent independently observes events in the local environment and communicates with other vision agents through the computer network. Since the vision agents do not have any constraints in the mechanism like autonomous robots, we can install a sufficient number of vision agents according to tasks, and the robots can acquire necessary visual information from various viewing points of vision agents.

Figure 3 shows a prototype of the distributed vision system. The model town, which scale is reduced to 1/12, has been made for representing sufficient reality of an outdoor environment, such as shadows, textures of trees, lawns and houses. Sixteen vision agents have been established in the model town and used for navigating mobile robots. The distributed vision system can memorizes tasks for navigating the robot along paths by organizing the vision agents and iterate to select proper vision agents for robustly executing the tasks in a complex environment.

The roles of the infrastructure are not only to provide information, but also to enable on-line debugging of systems. The purpose of Town Robot is not to develop a completely autonomous system. A robust system used in a real world sometimes needs helps of human operators. Human operators can monitor robot behaviors and send commands to the robots through the computer network of the infrastructure (See Figure 5).

3.2 Evaluation

If a system has a single purpose, the evaluation criteria can be easily determined. However, it is basically difficult to evaluate a system which has multiple purposes. The town robot system also needs to evaluate multiple tasks emerged through interactions with humans. For the evaluations, the system requires the following two functions.

1. Recognizing tasks emerged between the system and humans.
2. Recording and reporting statistical data for task evaluation.

These functions enable to relate robot tasks closely with human behaviors interacting with the robots and to evaluate the complex robot tasks. The results of the evaluation is fed back for the on-line system improvement.

An example of the system configurations is shown in Figure 8. In the town robot system, the task evaluation is executed by the evaluation modules. The operator generates new robot behaviors for necessary tasks by updating the context modules (The context module can be considered as an extended behavior module or a planning module which works in a limited situation. Section 4.3 discusses in detail) . The evaluation module records executions of the context modules and gives information, which tells what is going on between robots and humans, to the operator.

In previous works for intelligent autonomous robots, we have never discussed on evaluation of robot systems. On the other hand, there exist many reports on evaluation of information systems in computer science. For example, we can find such reports in proceedings of Int. Conf. Computer-Human Interaction. This means importance of evaluation in development of social systems.

Another important issue in the evaluation is that if we can find relations between human and robots and influence of the robots to the human societies. Rresults of evaluation must represent human-robot relations and give important information for understanding human societies in which robots work. We expect to be able to indicate cognitive maps on robot-human interactions.

3.3 Human interface

The town robot system shown in Figure 5 needs two types of interface:

- Operator-robot modules interface
- Robot-human interface

Figure 4 shows them.

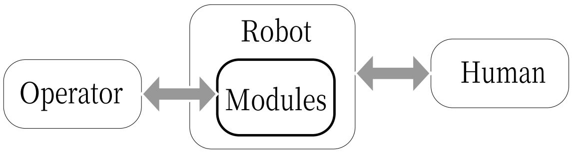

Figure 4: Interfaces for town robot systems

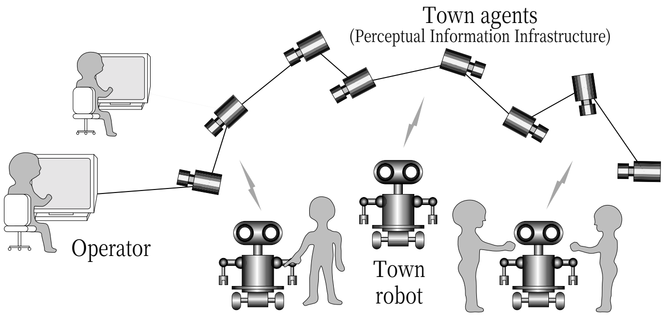

Figure 5: Conceptual figure of the town robot system

The town robot system have to never halt in order to be used in human societies. For supporting robots, a human operator sometimes intervene into the system and helps the robot solve problems. Therefore, the mechanism of operator's intervention should be embedded in the town robot system.

As shown in Figure 8, the operator monitor the system behavior through the computer network and update robot functions by adding new context modules. The operator refers reports from the evaluation module and programs the new context modules. The system would be able to extend such that contexts are automatically generated with some learning method. For example, it is not so difficult to implement a function which monitors the evaluation modules and generate new contexts by fusing the context modules.

With the context modules, the town robot system can realize another human interface. The operator can program context modules for asking helps to humans who are in a town. That is, the town robot system can access humans and human society through the context modules which are given according to various situations.

4 Development of a town robot system

4.1 Design of a town robot system

Figure 5 shows a conceptual figure of the town robot system. Although the robots have autonomous behaviors, they can be controlled and maintained their functions by the operators through the perceptual information infrastructure. The perceptual information infrastructure works as both extended sensors of the robots and a computer network to support communication between the robots and the operators. The system needs the infrastructures for realizing a robust robot system.

4.2 Hardware configuration

According to social robotics concept, we have developed a robot test bed. The robot is self-contained and mobile with wheels. The system hardware is shown in Figure 6. The robot has a hexagon-piped form. The locomotion mechanism and vision sensors are attached on the bottom and the top of the hexagon-pipe respectively. The size is about 1.35 meters tall including the sensors and the wheels. The width is about 0.6 meters diameter.

Three cameras are attached on the top of the robot as main sensors. A pair of cameras work as a stereo vision. The third camera is specially designed to acquire omni-directional visual information. These vision sensors can rotate with three degrees of freedom, roll, pitch, and yaw by a camera controller. With the vision sensors, the robot can actively obtain visual information which is necessary for visual navigation and interactions with humans. In addition to the vision sensors , collision detection sensors are attached around the robot. They are six touch sensors fixed at the both end of the pipe body along hexagon sides, so the robot has totally twelve touch sensors.

The robot has two pairs of wheels in both right and left sides, and totally four wheels are attached. Two wheels of a pair are chained and driven by one motor. The wheel consisting of eight ellipsoid cylinders specially designed for turn motion. That is, the robot can turn by giving different velocities to the motors. The robot has a special mechanism for posture stabilization. The differential gear mechanism is employed for mounting wheels so that the robot can stand almost upright even when the robot moves across small steps or on irregular terrain.

In the robot body, a single board computer, a vision preprocessor, motor control units, and batteries are equipped. The PC is responsible to all of sensor data processing, decision making, and motor control. All the sensors are connected to the computer I/O bus, and velocity signals are sent to the motor control units.

In addition to the on-board sensors, the robot can utilize sensory information provided by perceptual agents distributed in environemnt. The robot equips a wireless network facility, which is used to communicate with the perceptual agents of the infrastructure which supports the robot and system operators. Figure 7 shows the perceptual agents, called *Town Agents*, specially designed for the town robot system.

4.3 Software architecture

A key features of our software architecture is interaction functions between the town robot, the town agents and the operators. Figure 8 shows the software architecture. The novel components are the context modules and the evaluation module.

The context module is similar to a planning module in previous systems, which controls activation of the sensor-action modules and refers to the representations. However, consistent or complete representations cannot be obtained in a complex environment. Therefore, planning

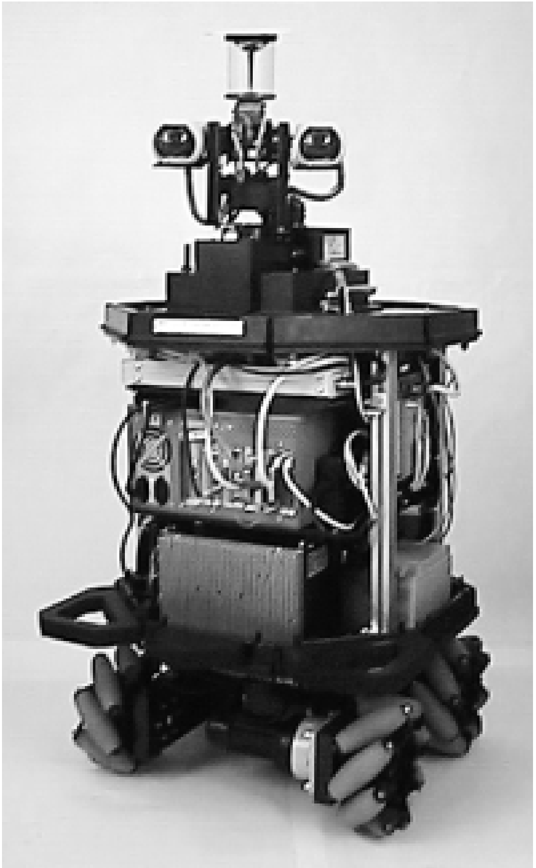

Figure 6: Town robot

Figure 7: Town agents

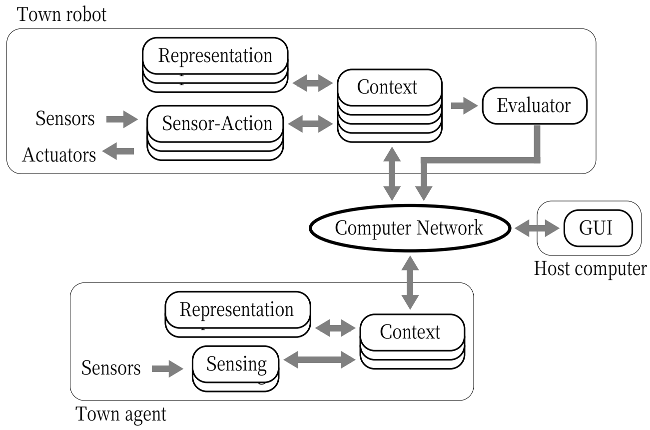

Figure 8: Software architecture

methods which have to deal with incomplete representations and noisy sensor data are required. The context module works in a specified situation defined with limited robust sensor data and builds local representations. The system uses the multiple context models according to the situations (The context modules can refer other context modules. That is, there exist a main context module which defines the execution orders).

The evaluation module monitors the context modules, records their executions and reports the record to the operator. The operator monitors the evaluation module, updates the context modules and adds new context modules by referring to the records. That is, the robot behaves according to the contexts given by the operators.

As discussed in previous sections, the system consists of robots (town robots) and perceptual agents (town agents). Utilization of the perceptual agents has another feature of this system. The perceptual agents help the robot in complex situations. They supplementary support the robot's sensing ability in the difficult situation. Sensor information obtained by the perceptual agents are sent via computer network to the robot, and the robot receives it as supplemental sensor inputs.

4.4 Research methodology

We employ a methodology which iterate experiment, evaluation and development in a short cycle for developing the town robot system (See Figure 9. We obtain system's behaviors in the real world by experiment, and improve the system by evaluating the experimental result. While iterating the process, we can adapt the system to human societies.

The most important issue in the system development is how to make the system grow. As a performance measure, *navigation distance* has been used in previous works. In contrast to the navigation distance, we employ *navigation time* as the measure. With long time existence of the robot, humans will be able to recognize robots, and with long time interaction with the robots, humans will be able to find tasks of the robots.

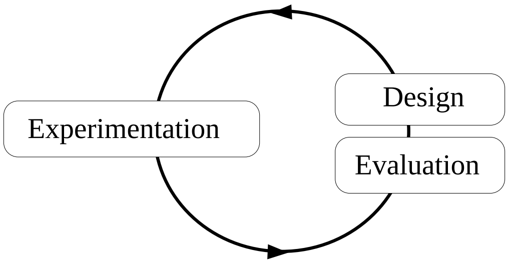

Figure 9: Methodology for developing the town robot system

We also employ size of working environment as an another measure of the system performance. As the system grow, the robot should adapt wider environments. We now consider three levels of environments such as indoor, outdoor-short, and outdoor-long. The term 'short' and 'long' refers both time and distance. The term 'outdoor' means ordinal non-hazardous environment in everyday life. In the indoor level, the system performance is still basic. In the outdoor-short level, robust sensor ability is required and operator-robot interactions will be the main issue . In the outdoor-long level, the robot acquires more chances to meet humans in streets, and human-robot interactions will be the most significant issue.

5 Conclusion

In this paper, we have discussed on technologies for developing town robots which works in human societies. The methodology of how to develop robot activity to support humans in human societies has different aspects from traditional one. We have proposed three important technologies for the town robot system: infrastructure, evaluation, and human interface. We have also discussed on hardware and software architectures of the town system and shown a prototype system.

Our goal is to unite robots and human social behaviors which have been separately studied in different research areas.

Acknowledgments

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