A Method for Human-Artifact Communication based on Active Affordance

Kazunori Terada*, **and Toyoaki Nishida****
*Synsophy Project, Communications Research Laboratory
2-2-2, Hikaridai, Seika-cho, Soraku-gun, Kyoto, 619-0298, Japan
kazuno-t@crl.go.jp
**The University of Tokyo
7-3-1, Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan
nishida@kc.t.u-tokyo.ac.jp

Abstract

The development of computer technology has created artifacts that have more complex and intelligent functions. Such artifacts need more sophisticated interfaces than primitive artifacts. In this paper, we discuss which characteristics are appropriate for interfaces with artifacts and propose a concept of *active affordance*. We describe an *autonomous mobile chair* that we built as a test bed for active affordance. We also describe a experiment that we performed with a real robot that show the validity of our proposed method.

Introduction

Artifacts have been created as a way of extending our abilities beyond our own bodies. We manipulate an artifact in the way that brings out the function which is peculiar to that artifact. When we use an artifact we need to convey our intention to it through some communications channel, such that the artifact 'understands' our intention and responds with some appropriate behavior. A human communicates with an artifact to convey his or her intention so that he or she controls the artifact in the desired way. In the extreme case, we might expected to treat an artifact as if it ware a set of limbs.

Communication is even needed in the case of the manipulation of a pair of scissors, a rather primitive tool. The intention of cutting a sheet of paper is generated, and we apply our hand to move the handle of the scissors. As a result, we cut the paper as we intended. In this case, the handle of the scissors acts as the interface where our intention is translated into functional motion. In the case of primitive tools such as a pairs of scissors, the manipulation of the artifact is directly related to the function.

However, the development of computer technology giving many artifacts more complex and intelligent functions. Such artifacts need more sophisticated interfaces than those of primitive artifacts. In this paper, we discuss the appropriate form for interfaces with artifacts.

Active artifacts

Artifacts have been evolving for a long time and continue to evolve. In this section, we discuss the evolution and the degrees to which they are active. In recent times some artifacts, for example, doors have been equipped with sensors and actuators and becomes an automatic door. We call such an artifact an *active artifact*. The active artifact will improve our life. Actuators are capable of reducing the load of our everyday work. It is expected that artifact of the next generation will be equipped with actuators and be capable of autonomous behavior. The characteristic of the active artifact is that it realizes its function autonomously.

We explain the characteristics of the active artifact by comparing the humanoid paradigm with the active-artifact paradigm. In recent years, there has been much effort toward the design of humanoid robots (Hirai *et al.* 1998)(Bischoff & Jain 1999). Humanoid robots may be most suitable artifact for the labor of our everyday work, because our living areas are designed with human usage. Humanoid robots are intended to perform the tasks required of humans. If we want to take a rest, we request that a humanoid robot bring a chair. However, in the active-artifact paradigm, the chair itself would come to us. We do not need a task-mediator such as a humanoid robot.

If the artifact is passive and does not move, we ourselves need to do everything for the task execution. However, if the artifact is active, the task is collaboratively executed by the human and the artifact. The main issue in designing an active artifact is working out how to communicate with it. We will discuss this issue in the next section.

Communication between Human and Artifact

The purpose of human-human communication is mutual comprehension and the knowledge sharing. On the other hand, the purpose of human-artifact communication is task sharing.

Model of communication

Figure 1 shows our model of human-artifact communication and the concept of active affordance we propose. The communication can be divided into the following parts.

- Conveyance of intention from the human to the artifact, which includes
  - aware communications, and.
  - unaware communications; and
- actions from the artifact to the human.

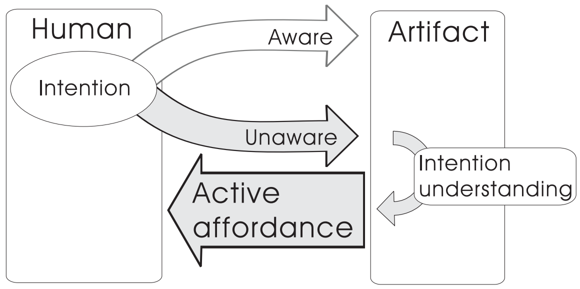


Figure 1: Communication between human and artifact

While human-human communication is bidirectional, human-artifact communication is mono-directional. A human has an intention when he is going to carry out some task. The intention is conveyed to the artifact through the communications channel. There are two modes for the communications channel; 1) aware communications, the means of which include natural language, sign language, and gesture and 2) unaware communication channel, which refers to nonverbal behavior.

If an artifact has a modality for aware communications, a human is able to use the channel for aware communications by utilizing the methods for human-human communication. However, the communications protocol should be predefined and the system needs a large database of vocabulary.

Some psychological researchers have concluded that more than 65 percent of the information exchanged during a face-to-face interaction between humans is expressed nonverbal (Argyle 1988). The unaware communications channel is important for human-human communication. Cassell pointed out that speech and nonverbal behavior join together to convey the communicative intent of a speaker (Cassell 2000). The unaware communications channel should also be important in human-artifact communication. Unaware communications is used as a means for conveying human intention in communications between humans and artifacts. An intelligent active artifact is able to completely understand the human's intention.

Active Affordance

The user's intention is revealed in unconscious motion. The action generated when a human manipulates some artifact varies according to the artifact's physical properties and functions. The artifact might take advantage of the peculiarities of the various forms of motion to detect the user's intention. The artifact then to complement the user's actions. We call such an action as *active affordance*.

The concept of affordance was introduced by the psychologist J.J.Gibson (Gibson 1979). Affordance refers to the possibilities for the action that available in the environment or the object, and which are revealed by interaction between the human and the environment. For example, the affordance of a chair is such that it allows to a human to sit on the chair, but is not manifested until the human generates the action of sitting down.

Although affordance in the original concept is realized by the user's action (Norman 1988), active affordance is realized by the artifact's action. Affordance which is not found by a human is meaningless. The reasons for affordance not being found are as follows.

- The function of the artifact is unknown.
- A user does not know how to use the artifact (the user is, however, conscious of his intention).
- A user is not even conscious of his intention.

Active affordance solves these problems.

Our implementation of the comprehension of intention

Our use of the aware communications channel and the unaware communications channel as means for the 'comprehension' of intention must be appropriate. In this work, we use the following methods.

Channel for aware communications

We use gesture as one means for aware communication. We thus compare the user's motion with a set of predetermined gesture pattern.

Channel for unaware communications

We use following heuristics to realize the unaware communication.

- Physical contact always occurs in object manipulation, and indicates a critical state.
- The distance between the surfaces of user's body and the artifact is reduced by the action of reaching.
- This reduction of distance indicates that the user intends to manipulate the given artifact.

Method of behavior generation

Once the intention has been 'understood' by the artifact, it should produce behavior that is appropriate in response to the intention. In this section, we describe the method used to generate such behavior.

Affordance distance

In the following sub-section, we describe an architecture which allows an artifact to autonomously realize its function. Firstly, we consider a method of describing the functional relation between a human and an artifact based on the concept of affordance. As was mentioned by Gibson, a physical relation and, in particular, relation of surfaces between the human's body and the environment is important for the human's behavior in physical world. Such a relation is described relative to the human's body as a standard. In order to describe the relation between the surfaces of a human's body and the surfaces of the object (artifact), we introduce the concept of *affordance distance*.

Affordance distance has a value and defined in the following way.

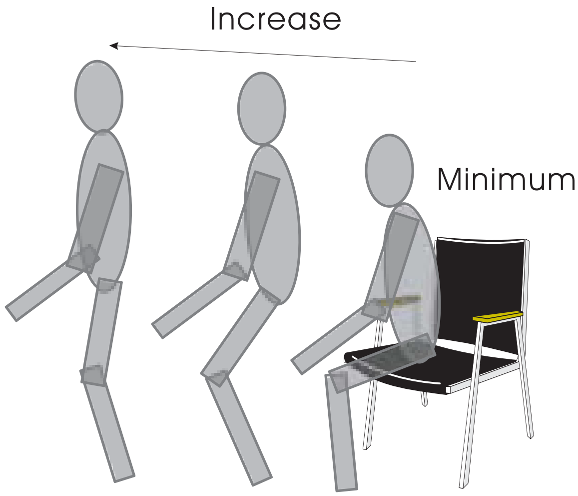


Figure 2: Affordance distance.

- Affordance distance will be as its minimum value at the end of an action sequence, i.e., a tactile state.
- Affordance distance increases as the agent becomes increasingly distant from the tactile state.
- Affordance distance is defined between a point on artifact's body and a point on the human's body.

For example, in the case of the chair drawn in Figure 2, the affordance distance will be minimum value when the human is sitting down, and will increase as the human goes away the chair. Affordance distance is not Euclidean but corresponds to the cost of the action which is required of the artifact when it goes to contact with human. That is because the optimal action path that minimizes the distance between two points is not necessarily the shortest distance. The optimal action path depends on the locomotive ability of the artifact and the relative angle between the two surfaces.

Calculation and minimizing of the affordance distance

The purpose of an artifact is to search for and move to a state where the affordance distance is at its minimum. In this subsection we describe a method for calculating the affordance distance and the method for controlling the artifact. We employ a utility function to express the affordance distance. The utility function is a widely used in a research in autonomous agents (Sutton & Brato 1998). The utility function is capable of representing the distance to the goal state, considering the locomotive ability of agent.

The utility value of each state is calculated by the following equation.

$$U(s) = R(s) + \max_a \sum_{s'} M^a_{ss'} U(s') \tag{1}$$

where M^a_{ij} is the transition probability of reaching state j if an action a is taken in state i. $M^a_{ss'}$ is obtained by the repetition of the same action from the same state;

$$M^a_{ss'} = \frac{n_{s'}}{n^a_s} \tag{2}$$

where n^a_s is the number of times of the action a which is carried out at state s, and $n_{s'}$ is the number of times the state s' is reached. $R(i)$ is a reward function which returns the value of the reward in state i. We give a reward when a certain point on the artifact's body comes into contact with a certain point on a human's body in an appropriate way, i.e., where the affordance distance is at its minimum. The tactile condition is

$$(x, y, z)_p = (x, y, z)_q \wedge (\theta, \phi, \varphi)_p = -(\theta, \phi, \varphi)_q. \tag{3}$$

where $(x, y, z)_p$ are the coordinates of the point on the human's body and $(x, y, z)_q$ are the coordinates of the point on the artifact's body and $(\theta, \phi, \varphi)_p$ and $(\theta, \phi, \varphi)_q$ are the angles of the normal vectors which are normal to the surfaces at the respective points.

In our method we use a simple iterative algorithm called *value iteration* to calculate the utility value of each state. The value iteration procedure is performed according to the following equation.

$$U_{t+1}(s) \leftarrow R(s) + \max_a \sum_{s'} M^a_{ss'} U_t(s'). \tag{4}$$

Where $U_t(s)$ is the utility value of s after t iterations. The utility value is known to converge to the correct value when $t \to \infty$.

Given a utility function U and if a state transition holds the Markov property, the optimal policy for the Markov decision problem is calculated in the following way.

$$f(i) = \arg\max_a \sum_j M^a_{ij} U(j). \tag{5}$$

Where $\arg\max_a f(a)$ returns the value of a that produces the highest value for $f(a)$.

Experimental results

To show the validity of our proposed method, we performed experiments using a computer simulation and a real robot. In this section we describe our experimental system and results.

Autonomous mobile chair

We have built an autonomous mobile chair as an example of the active artifact. The purpose of the autonomous mobile chair is to reach its back reclining on human's back.

We remodeled some parts of an aluminum chair to allow it to move around (See Figure 3). The chair has five legs, radiating in every-spaced directions, and each leg has a caster which freely rotates in the horizontal plane. In our system, we replaced two of the casters with powered wheels, each of which is fixed to the leg. The autonomous mobile chair is equipped motion-capture system made by Ascension Technology, which enables measurement of the position and orientation of the chair's body. The motion-capture system employs pulsed-DC magnetic-field transmission and sensing technology to measure the positions and orientations of miniaturized sensors that are attached to the measuring equipment. The autonomous mobile chair is controlled by a Linux PC to which it is connected via RS232C cable. A subject in this experiment also has to carry a motion sensor so that the autonomous mobile chair is able to determine the reaching point.

Figure 3: The autonomous mobile chair.

Modeling of the autonomous mobile chair and state space

In order to perform computer simulation, the environment and the autonomous mobile chair ware modeled in the following way. The environment is a floor of $5m$ square. The size of the chair and the arrangement of its wheels is as shown in figure 4. The state space is constructed in the following way (see figure 5). To simplify the simulation, we assume that the dimension of two for both the autonomous mobile chair and the environment, that is, height is disregarded and the artifact is able to only move in the 2D plane. As a result, the dimension of the state space is three; (x, y, θ). The floor is divided into a 50×50 grid. The angle of the normal vector of the surface is discretized into 16 steps. As a result, the discrete state space has $50 \times 50 \times 16$ states. We also assume that we are able to send six action commands to the autonomous mobile chair. The commands are executed by specifying the speeds of the motors. The commands are $A1(-V, V)$, $A2(0, V)$, $A3(V, V)$, $A4(V, 0)$, $A5(V, -V)$, and $A6(-V, -V)$. In this experiment, V is $0.3m/sec$. We define the action unit as the segment of the artifact's motion that precedes the observation of a change of state.

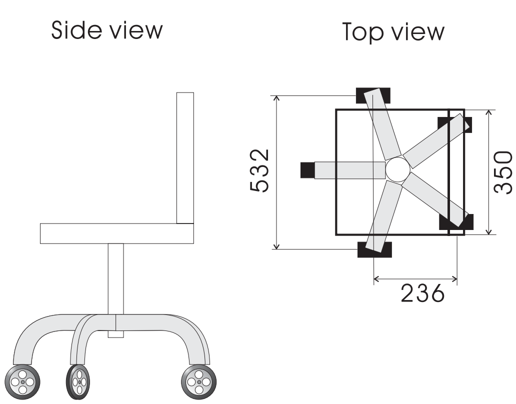


Figure 4: The model of an autonomous mobile chair.

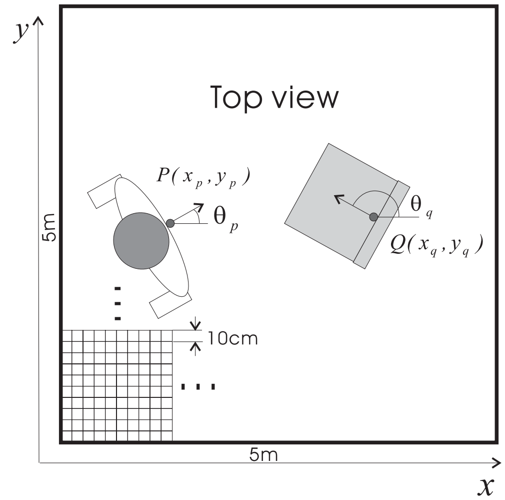


Figure 5: The model of the environment and state space.

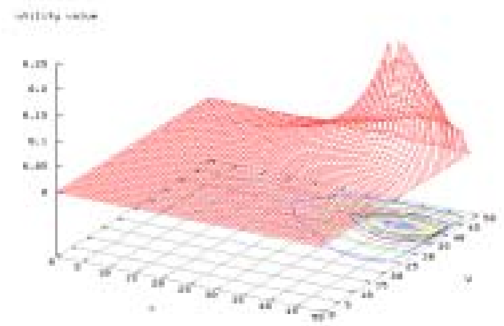
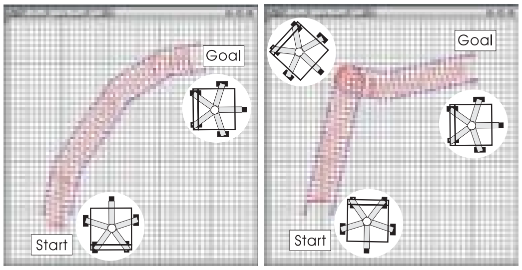


Figure 6: The utility function. The goal state is $(40, 40, 0)$. The utility value is the mean value for the 16 states of θ.

Calculation of utility value

Firstly, we calculated the transition probability model. Each of the six action commands is executed from 100 uniform points in a grid, i.e., n_s^a in equation (2) is 100. This operation is performed for each of the 16 angles. The transition probability model for a certain one grid position is applied to other grid position since the transition probability is equal for every grid position.

Next, the utility function is calculated. The goal point, i.e., the point of contact, is set as $(40, 40, 0)$. The reward



(a) Start: $(10, 10, -\pi/2)$ (b) Start: $(10, 10, \pi/2)$

Figure 7: Generated paths.

Figure 8: Intention understanding and behavior generation

given for reaching the goal point has a value of 1. Figure 6 shows the utility function as calculated by using the dynamic programming algorithm.

Reaching the goal

To show the validity of the calculated utility function, we carried out two cases of reaching experiments in computer simulation. One of the cases, i.e., case (a), is that where the state of starting point is $(10, 10, -\pi/2)$ while in the other case, i.e., case (b), the state is $(10, 10, \pi/2)$. Figure 7 shows the paths generated in the two cases. In case (a), the autonomous mobile chair changes direction gradually as it approaches the goal. In case (b), the autonomous mobile chair reverses once, changes direction, and then proceeds to the goal. In both cases, the autonomous mobile chair generates an appropriate path and reaches its goal.

Comprehension of intention and generation of behavior

Figure 8 shows an experiment in the comprehension of intention and generation of behavior. The subject generates a beckoning gesture: palm down, the hand flaps at the wrist. The gesture is perceived by the autonomous mobile chair through its motion capture system. The chair then moves to the subject.

Conclusion

In this paper, we discussed an appropriate interface for artifacts and proposed the concept of *active affordance*. Active affordance is valid in the following cases:

- where the functions of the artifact are unknown;
- where the user does not know how to use the artifact;
- where the user is not conscious of even his intention.

To realize active affordance, we introduced the concept of *affordance distance*. We employ a utility function to express the affordance distance. We built an *autonomous mobile chair* as an example of an active artifact that embodies the principles stated above. To show the validity of our proposed approach, we carried out experiments by computer simulation and real robot. Our experimental results show that the autonomous mobile chair is able to generate an appropriate path to the goal by means of the acquired utility function. We can thus safely say that the affordance distance is a suitable means for the realization of implicit communication. We also gave a result of an experiment in the comprehension of intention and the generation of behavior.

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