# Robovie-IV: A robot enhances co-experience

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## Abstract

*People establish and enhance their social relationships through sharing experiences with others. Among media used to promote such experiences, a human-size humanoid is the most promising medium. In addition to capabilities of other media, such as the ability to collect and provide information from the Internet and via ubiquitous sensors connected through a network, a human-size humanoid has the potential to help people share experiences or information among them owing to its shape. It enables people to accept a sense of humanlike expressions or emotions, wishes, and so forth. We have recently developed a human-size humanoid, called "Robovie-IV," as a ubiquitous medium to enhance co-experience. This paper discusses the design requirements of Robovie-IV and introduces an overview of its hardware and software architectures. There is also a brief description and preliminary results of an experiment that we are currently conducting with Robovie-IV, in addition to conclusions.*

## 1. Introduction

A person's experience often compels the person to improve the quality of her/his activities, and such an experience may be utilized by other people. Therefore, sharing an experience or knowledge on an experience is important. Moreover, experience sharing or co-experience can serve to establish or to enhance social relationships among people. However, a person may sometimes hesitate to participate in a novel experience or may not have a novel experience merely because of the person's ignorance of its existence. Facilitation of experience is important, and this can usually be achieved upon recommendations by other people or by obtaining knowledge about a particular experience from some media such as books, Web pages, and television. Are these the only possible media? No. In fact, one of the most promising candidate media is a humanoid robot whose size is similar to that of humans. It's potential partly lies in its shape, which allows for a sense of human-like expressions or emotions, wishes, and so forth. We can envision a future scene where humanoid robots cohabit with us ubiquitously to facilitate co-experience or as ubiquitous (co)experience media.

We have been developing a series of communication robots called Robovie to investigate how a robot can serve to facilitate experience and co-experience. Based on knowledge obtained in the process of developing the previous Robovies, we have developed Robovie-IV as an ubiquitous experience medium to enhance co-experience in human-human and human-robot-human settings. In the next section we discuss what is necessary for a robot as an ubiquitous experience medium and describe the design concept of Robovie-IV. Then we present an overview of Robovie-IV's hardware and the software architecture. Following that, we show an experiment we are currently doing with Robovie-IV and finally give conclusions.

## 2. A robot enhances co-experience

What kinds of capabilities are necessary for a robot as a ubiquitous experience medium? There are at least the following requirements to achieve natural and effective human-robot communication. First of all, it should be self-contained. Although its computers, database systems, and even sensors can be outside of its body, it should have mechanisms to perform both verbal and nonverbal communica-

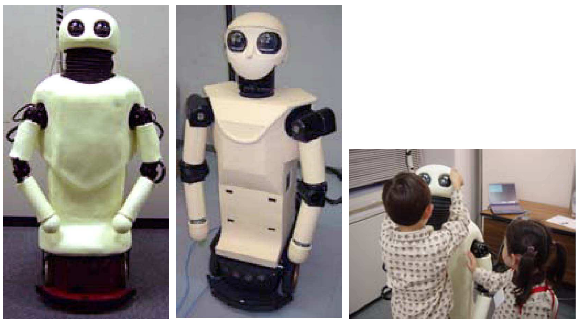

**Figure 1. From left to right, Robovie-IIS, Robovie-IIF, and haptic interaction between children and Robovie-IIS.**

tion by itself. It should be able to move around with no wires for smooth communication because the distance between a person and a robot cannot be ignored in order to achieve effective communication. Also it should not have an outward appearance that frightens or discomforts people.

Second is the capability of haptic communication. Haptic communication is as important as vision and voice. People who are familiar with each other often touch each other's hair or hug each other; such haptic interaction reinforces their familiarity. If a communication robot equipped with tactile sensors over its entire body could have the same capability of haptic interaction as human do, the robot would give us greater familiarity, thus shortening its communicative distance from people. To study haptic communication, we have previously developed two types of humanoid robots, Robovie-IIS and Robovie-IIF, that have tactile sensors embedded in a soft skin that covers the robot's entire body [8]. These robots were developed based on Robovie-II [5]. Figure 1 shows overall views of Robovie-IIS, Robovie-IIF, and a scene of communication with a human. Robovie-IV has tactile sensors based on the technique we used for these robots.

Third is the locomotion mechanism that can generate involuntary motions. Human motion can be classified into two types: voluntary and involuntary motion [1, 10, 2]. Voluntary motions are a set of motions made to achieve given tasks or intentions. Going to a certain place, moving an arm forward for a handshake, vocalization to say hello, and reacting to a pat in order to know who did it are such examples. Involuntary motions, on the other hand, are a set of incidental motions such as feedback control arising in response to physical stimuli from the environment without prior planning or motivation. These motions do not correspond to tasks directly but instead consist of motions that make the robot appear to behave more naturally. Robovie-III was developed to enable involuntary motion for a robot [7]. It uses a wheeled inverted pendulum mechanism for locomotion. Since the inverted pendulum is controlled by feedback on its posture, involuntary motion of the whole body occurs. In addition to effecting involuntary motion, the wheeled inverted pendulum has a unique feature: When some external force is applied to the body from its front, it moves backwards. Since its wheels are controlled to maintain its posture, it moves backwards to keep the posture as it tilts backwards due to the applied force. We also adopt the wheeled inverted pendulum mechanism for Robovie-IV.

Fourth is human recognition. People expect a robot to be able find and identify them. On top of that, to be able to share the memory of co-experience with humans, human identification is mandatory. Many methods for human detection and identification using images have been proposed; however, with current computational power and video camera resolution and viewing angles, conditions under which those methods work are still limited. Consequently, we decided to use a laser range sensor to find human leg candidates and an optical/RF tag system for human identification. Robovie-IV finds leg candidates using a laser range sensor, verifies the results with its camera, and identifies the detected human with a tag.

Based on the above discussion, Robovie-IV is designed as a robot 1) whose height is the same as a child's; 2) whose whole body is covered with soft, light-colored skin for a soft look and touch; 3) with many tactile sensors are embedded in the soft skin; 4) which can move in two modes, one is a normal wheeled robot mode with passive casters, and the other is the inverted pendulum mode; and 5) which has optical and RF tag readers and laser range sensors for human identification.

## 3. The hardware architecture

Figure 2 shows front and side views of Robovie-IV. The height of the robot is about 1 m, which is smaller than Robovie-II/II-S/II-F (which are 1.2 m high). As in the figure, it has two arms which have four dof each, one head with pan, tilt, and roll joints, four spare wheels (passive casters), two powered wheels, and one jack to enable the inverted pendulum state. Robovie-IV is equipped with two video cameras with pan and tilt joints, one camera with an omnidirectional mirror, a microphone and a speaker, an optical tag reader (easily detachable, not shown in the figure), an RF tag reader (the system is based on the active tag system called Spider by RF Code Inc. [11]), two laser range sensors in the front and back, two gyros that sense the same axes (we use two to take the average of their outputs in order to reduce random noise, and to detect failure so that the robot does not fall over), and 56 tactile sensors. Figure 3 displays the arrangement of the sensor elements that are em-

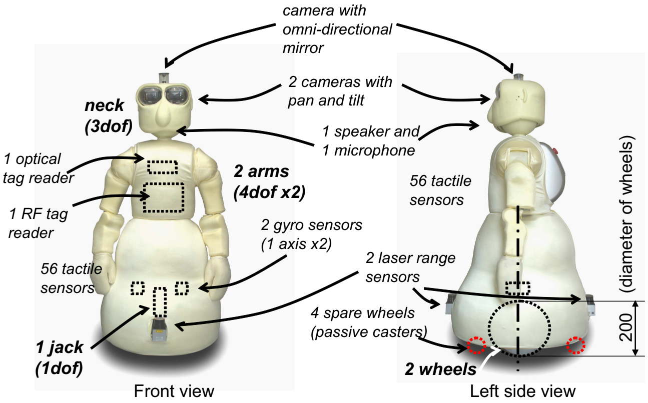

**Figure 2. Front and left-side views of Robovie-IV. Fitted actuators and sensors are shown.**

bedded in the soft skin. The figure clearly shows that there are tactile sensors under the nose, ears, and in the thumbs for Robovie-IV to sense contact to those areas.

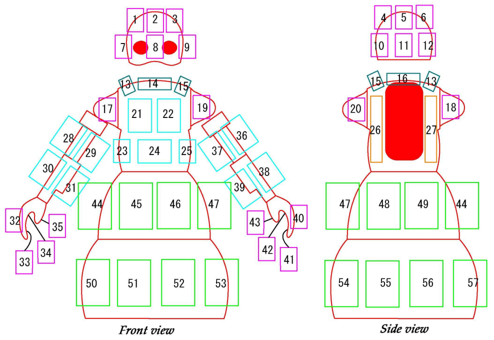

**Figure 3. The arrangement of the skin sensor elements. There are 56 sensors in its soft skin (#16 is not implemented).**

Figure 4 shows Robovie-IV's hardware architecture. There are four PID motor controllers connected to a PC via RS-232 dedicated for wheels, left and right arms, and neck joints. The jack and the inverted pendulum are controlled by the motor controller. Two laser range sensors and optical and RF tag readers, and cameras with pan/tilt joints are also connected to the PC via RS-232. Signals from the tactile sensors are fed to five skin processors. The processed signals are then sent to the PC via the RS-422 bus. Images from three cameras are captured by a frame grabber installed on the PC. A speaker and a microphone are connected to the sound output and input of the PC. Each controller has a SH2 micro-processor (Renesas Technology Corp.) and the main computer has a Pentium-M processor that runs at 2 GHz. The PC can be connected to the sensors via a wireless LAN.

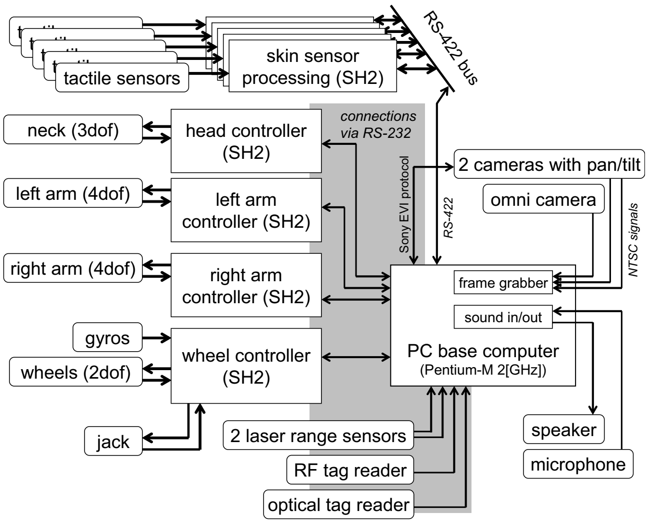

**Figure 4. Robovie-IV's hardware architecture. There are four motor controllers, five skin processors, and one main computer.**

Figure 5 shows the structure of a tactile sensor element embedded in the soft skin. As the figure illustrates, the soft skin consists of four layers. The outside layer is made of thin silicone rubber, and the middle layer is made of thick silicone rubber. We use these silicone rubber layers to realize humanlike softness. The inner layer is made of urethane foam, which has a density lower than that of the silicone rubber; the densities of the urethane foam and the silicone rubber are 0.03 g/cm$^3$ and 1.1 g/cm$^3$, respectively. The total density of the soft skin consisting of all layers is 0.6 g/cm$^3$. Robovie-IV's tactile sensor elements are film-type piezoelectric sensors inserted between the thin and thick silicone rubber layers. These film-type sensors, consisting of polyvinylidene fluoride (PVDF) and sputtered silver, output a high voltage proportionate to changes in applied pressure. Since the middle and the inner layers deform easily upon human contact with the skin, the sensor layer can easily detect the contact.

Figure 6 illustrates how the powered wheels, the spare wheels, and the jack are connected. The spare wheels are connected to the main body directly, while the powered wheels are connected via the jack. Robovie-IV can select two locomotion modes, with or without spare wheels, by controlling the jack. With the spare wheels, Robovie-IV moves as a normal robot with two powered wheels, but without them, it moves in inverted pendulum mode. We utilize the wheeled inverted pendulum controller proposed

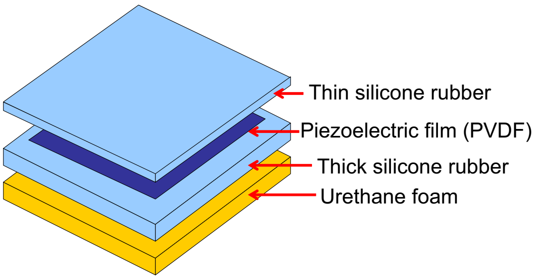

**Figure 5. The skin's structure, which consists of four layers. The piezoelectric sensor is inserted between the outer and middle layers.**

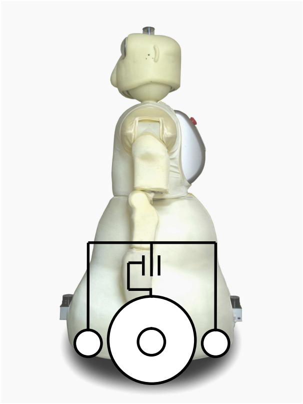

**Figure 6. The powered wheels are connected by a jack to the main body and spare wheels. The figure shows the inverted pendulum mode.**

by Ha and Yuta [4].

## 4. The software architecture

Figure 7 presents an overview of Robovie-IV's software architecture. The OS on the PC is Linux and a box with bold line in the figure indicates a process running on Linux. There are six processes, *robovie4, robobase4, robomap4, robocam4, PostgreSQL*, and *julian*. The processes are connected through FIFOs, sockets, and shared memories. The process *robovie4* makes decisions for the robot from the internal state, information on the database, and the sensor information gathered and processed by the other processes. Processors on the motor controllers control motors as directed by the program called *robobase4* running on the PC. Process *robobase4* handles the communication between controllers and sensors, while *robobase4* hide the differences of the protocols from the *robovie4*. Process *robomap4* is the one for self-localization. It receives information from the two laser range sensors and odometry from *robobase4* and compares it with the map of the environment. The estimated position is returned to *robobase4* and sent to *robovie4*. Then, *robocam4* processes images from the cameras. The processed results are directly sent to *robovie4*. The PostgreSQL [13] is a popular database engine. We use the database store and recall the co-experiences with humans.

The julian process is a process of a grammar-based recognition parser named "Julian." Julian is a modified version of Julius [6], which is a high-performance, two-pass large-vocabulary continuous speech recognition (LVCSR) decoder software for speech-related researchers and developers. We have prepared manually-designed DFA grammar as the language model and use it for the speech recognition by Julian. The *robovie4* process connects to the *julian* process and commands the selection of dictionary and so on. The recognized words are sent back to *robovie4*.

### 4.1. Writing programs for Robovie-IV

The *robobase4* process mainly consists of an event handler written in C++ and tasks written in Lua [12]. Lua is a scripting language that can be embedded in a C or C++ program. Although we can write the whole program in C++, we adopted a hybrid approach that enables us to write tasks interactively. Tasks written in Lua run in parallel by the collaborative multithreading supported by Lua.

The events from sensor values are detected in the event handler, negating the need to copy an event detection for each task. The event handler in *robobase4* repeatedly 1) collects sensor values from *julian, robocam4,* and *robobase4*; 2) detects events; 3) sends events to tasks; 4) receives commands from tasks; and 5) sends commands to *robobase4* as in Fig. 7.

The tasks repeatedly 1) waits for events from the event handler; 2) reads sensor values sent from *robocam4*, *julian*, or *robobase4*; reads from and writes to the database; and 3) decides the next action. Figure 8 shows an example task written in Lua. It repeatedly and infinitely 1) waits for touch events; and 2) prints out "touch" infinitely. From the example, it is clear that we can write the waiting for an event in a sequence, unlike in other objected oriented approaches such as OPEN-R [3]. We decided to use this approach since many robot tasks can be easily written as sequences of behaviors.

### 4.2. Processing tactile sensor signals

Figure 9 shows the raw data from a tactile sensor for four kinds of touch behaviors by one of the authors. From

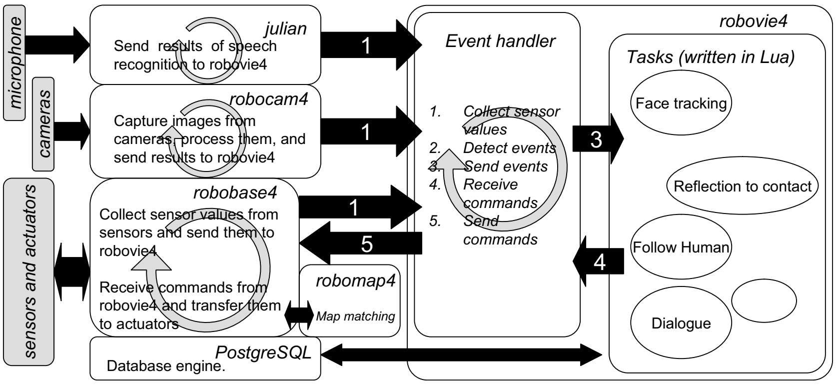

**Figure 7. Robovie-IV's software architecture. The PC's OS is Linux. There are six processes robovie4, robobase4, robomap4, robocam4, PostgreSQL, and julian.**

```
function task1(co)
  local self = TaskTable("task1",
                         co, task1)
  Register(self)

  while (1) do
    CatchEvent("R4Touch", self)
    SleepTask()

    print("Ouch");
  end
end
```

**Figure 8. An example task written in Lua. It repeatedly and infinitely 1) waits for touch events; 2) prints out "touch."**

the figure we can see that four behaviors create clearly different signals for the tactile sensor. We use the word "no touch" to indicate that he did not touch the skin, and "still contact" to indicate that he just placed his palm on the skin right on a sensor element. At this time, though the signal is very weak, we can see the induced signal from the power line (60 Hz in our case). We use "hit" to indicate that he hit the skin on the sensor element. We see a strong impulse, which means the signal has a wide spectrum including higher frequencies. We use "stroke" to indicate that he stroked a part of the skin close to the sensor element. We see that the signal is strong but it is not as "peaky" as the "hit" signal. With the above knowledge gained from our experiment, we have implemented the tactile classification program onto the skin sensor processor. The tactile sensor output is read and processed at 200 Hz. Every time the processor reads the signal, it classifies the signal by the algorithm shown in Fig. 10. It first checks whether the signal is classified as "no touch"/"still contact" or "stroke"/"hit" by the signal's strength. If the signal is weak, it checks the correlation to the 60 Hz sine wave, and if the correlation is high, the current signal is classified as "still contact"; otherwise, "no touch." If the signal is strong, it checks the output of BPF (five-order BPF, low and high cut-off freq.: 70 Hz and 100 Hz). The results are sent to the host PC via the RS-422 serial bus. We have implemented and tested these sensor processes, and found the results satisfactory. Although this process is very simple to implement, we believe that the four behaviors covered by it are the most important ones in tactile communication.

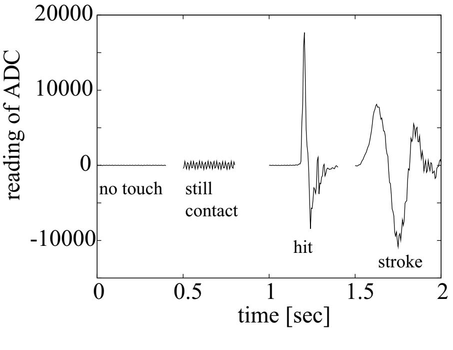

**Figure 9. The raw data from a tactile sensor for four kinds of touch behaviors by a human.**

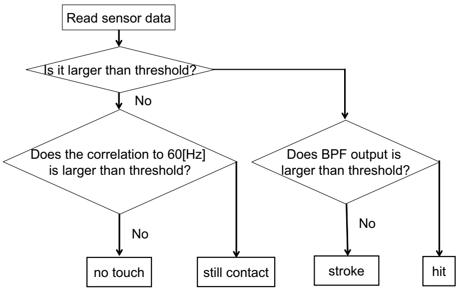

Figure 10. The algorithm to classify the tactile sensor signal.

## 5. What do people feel about involuntary motion?

As we have stated earlier, involuntary motions are important for natural communication. However, different controls give different impressions since an involuntary motion incidentally arises from the system's control mechanism.

We have prepared three different controls for the inverted pendulum. Figure 11 shows the characteristics of the three controls when the robot is pushed by a force of the same strength from the forward to reverse direction. The first one controls the wheels to keep the body in a certain position and the velocity to zero. The robot is pushed and starts moving at 2 s, goes backwards to -0.4 m behind its initial position, then gradually returns to the first position to which it was moved. Note that in the graph, it seems that the robot moved forward immediately after the push. However, this just indicates the wheel's rotation forwards in order to compensate for the rebound, not the real movement. The second one controls the wheels to keep the body in a certain position and the velocity to zero, while the desired position changes to -0.3 m after the robot feels the push. The figure shows that the robot gradually goes back to -0.3 m after the push. The third one controls the wheels to keep the body velocity to zero. This one does not maintain the position. The figure shows that the robot goes back, gradually slows down, and stops.

We gathered 15 subjects and asked five of them to push the robot with control 1, five to push it with control 2, and five to push it with control 3. We asked them to fill in a questionnaire after they had pushed the robot until they understood its movement (most of them pushed two or three times). We prepared the questionnaire to explore how each subject feels about the robot's personality. According to the five-factor model [9], the personality of a human is composed of five factors, that is, extroversion, agreeableness, conscientiousness, neuroticism, openness, and intellect. Murakami and Murakami [9] found Japanese adjectives relevant to those factors. In the questionnaire, we placed three pairs of adjectives for each personality factor from their adjective list (15 pairs in total) to conform to the themantic differential method. The pairs of adjectives were presented at either end of a seven-point scale. For example, 'dumb' was placed at 1 on the scale, while 'lively' was placed at 7.

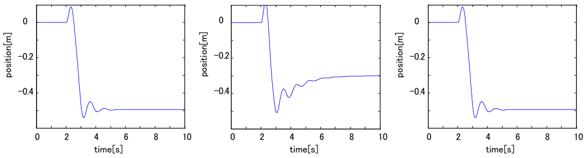

Figure 11. The characteristics of the three controls.

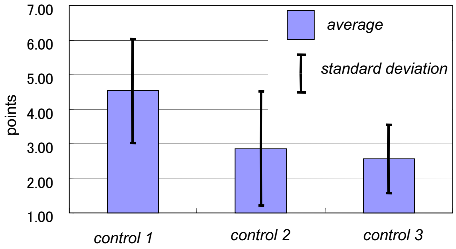

Figure 12. The points of controls for adjective pairs relevant to the extroversion factor.

As a result, we found that three controls differ with respect to the extroversion factor. Figure 12 shows the points of each control. The point is the average of the adjective pairs relevant to the extroversion factor for each of five subjects. We see that the subjects felt greater extroversion from control 1 than from controls 2 or 3. Although these are still preliminary results, they do indicate that involuntary motions are important factors in communication.

## 6. Conclusions

We have developed a human-size humanoid, called "Robovie-IV", as a ubiquitous medium to enhance co-experience. We discussed what is necessary for a robot as an ubiquitous experience medium and described its design concept. Next, we introduced the hardware and software architectures of Robovie-IV. It has also been developed as a self-contained robot that fulfills the requirements for a ubiquitous experience medium. That is, Robovie-IV is as tall as human child, its whole body is covered by a soft-skin containing 56 embedded tactile sensors, it locomotes by an inverted pendulum mechanism that causes involuntary motions, it has sensors for human recognition, and it has a database system to memorize co-experiences with humans. In addition, we introduced an experiment on involuntary motion, with the results revealing that the involuntary motions could be one of the most important factors in human-robot communication. We believe that the Robovie-IV's architecture will be the basis of ubiquitous experience media to enhance co-experience.

## Acknowledgement

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