Steps towards Affordable Android Telepresence

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ABSTRACT

An important motivation for achieving effective embodied robotic telepresence comes not only from application areas where the robot will be teleoperated all of the time, but also, as we shall argue, in cases where the current state of the art of autonomous AI can cater for a significant percentage of the operating time of the robot, but is not yet good enough to support the application alone. The main motivation for the system presented here comes from such cases where adjustable and sliding autonomy can be applied, and more specifically towards applications of androids in shopping malls, as receptionists, tutor robots etc. In the system presented in this paper, the arms, neck, facial expressions, eyes, lips and voice of the Ibn Sina android robot are controlled on the basis of the body movements and voice of a remote operator, while the operator is experiencing the world through the eyes and ears of the robot, fed to a head-mounted display and headphones. The system is the first android telepresence system using very-low cost operator interface equipment (kinect and webcam) while supporting arm, neck, and expression control. We present a set of generic requirements, followed by an extensive description of our system architecture, video demonstrations of actual operation, a discussion, and multiple interesting extensions.

Categories and Subject Descriptors

I.2.9 [**Artificial Intelligence**]: Robotics – *Operator Interfaces*, H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *User interface management systems, Interaction styles.*

General Terms

Design, Human Factors

Keywords

Robotic Telepresence, Android Robots, Human-Robot Interaction

1. INTRODUCTION

In many application areas of android robots, the current state of the art of AI is not adequate for covering all possible interaction scenarios with a human, within the domain of the application. For example, the current state of the art of dialogue systems for robots, is inadequate for dealing with broad, generic natural language interactions; also, vision systems for robots, although having advanced in the last decade, still are far from being able to provide adequate capabilities for highly unstructured and varied environments. However, in a number of application areas, for example shopping mall robots [1], robo-receptionists [2], tutor robots [3] etc., the current state of the art is good enough for covering a percentage of human requests, even more so if careful interaction design reduces the overall generality, and task- as well as other forms of context enable further disambiguation and targeting. However, still, there will often be cases of human requests which will not be able to serviced by the robot autonomously.

Thus, one attractive possibility for bringing robots to the real world in such cases, and making them usable in real applications, is to tele-operate the robots by a remote human operator for a fraction of their time; i.e. only when a request is made to the robot, which its AI module cannot handle. By doing so, one can not only make the robots functional for the application domain targeted, but could also potentially achieve a number of other benefits: For example, if there is adequate idle time and a large enough percentage of the interactions can be covered by the robot autonomously, one can have a single human controlling multiple robots remotely, when his assistance is requested. This could lead not only to significant cost savings as compared to covering the application with humans only and without robots, but could also enable the human operators to live in a less expensive or more naturally appealing environment, to avoid commuting and thus reduce environmental degradation, etc. Also, situated responses of the human operators could be recorded and used as training data in order to increase the capabilities of the autonomous system through appropriate machine learning techniques.

If the human is to take over control of the robot for a period of time, not only a human-to-robot control link is required, but also adequate feedback must be provided, ideally enabling the human to be effectively “embodied” in the remote robot body, and achieving “telepresence”. It is worth noting that there are at least two different sides to the psychological content of “telepresence”: first, the operator could subjectively feel “embodied” in the robot, ideally also achieving at least some level of “body transfer illusion” [4], and second, other people interacting with the robot, could also subjectively have a feeling of human presence coming through the robot. Of course, in order to achieve such a state of affairs, there are specific technical requirements; many of which are the main subject of investigation in current robotic telepresence-related research.

In this paper, a real-world example of an implemented android tele-presence system is described, whose design was driven by a number of basic requirements initially imposed. The example uses the Ibn Sina robot ([5,6]), an Arabic-language conversational android robot, and which was initially designed as part of an interactive theatre with multiple possibilities for human teleparticipation [7]. In our system, the arms, neck, facial expressions, lips and eyes of the humanoid are controlled, while the operator is experiencing the world through the eyes and ears of the robot, fed to a head-mounted display and headphones. Initially, the operator-sensing apparatus was centered around a motion capture system, but in the latest versions affordable instrumentation based on the Kinect controller [8] was successfully utilized, in conjunction with other vision-based sensing, effectively making the operator-side apparatus easily portable and bringing down its cost immensely.

Regarding the structure of this paper, we will start with a background section, and then proceed with an introduction of a set of basic requirements, and an extensive description of our derived system. Then, a discussion section is presented, including potential extensions, and then we reach the concluding section.

2. BACKGROUND

In this section, basic background is provided on teleoperation and the current state of robotics application areas, as well as on adjustable and sliding autonomy, android telepresence, as well as on relevant psychological phenomena.

Robotics is an area that has advanced immensely in the last decades, and robots are now appearing in a *multitude of application areas*, beyond the traditional, such as industrial and manufacturing. Robots are now used in the household (such as the Roomba), in military applications (for example, the Boston Dynamics Big Dog), in schools (Lego Mindstorms), as well as in many other domains such as demining, search and rescue, the oil industry, and much more. Robot *body forms* vary; among the most popular forms are vehicle-like mobile robots (such as the popular Pioneer Robots), manipulator arms (for example, Puma industrial arms), as well as humanoids (such as the Asimo Robot). Humanoid robots which resemble human appearance closely are often called androids (for example, the Geminoid Robot [9]).

Furthermore, apart from form, robots vary across a wide spectrum in terms of *autonomy vs. human control*. Numerous application domains of robotics cannot be covered by today's state-of-the art in autonomous intelligent controllers, and thus there is a need for human intervention. Furthermore, some of these domains make the physical co-presence of human operators nearby the robot difficult or inefficient, and thus create the need for some degree of remote tele-operation – which could vary on a whole range including direct tele-operation and supervisory control [10]. Such application domains of robot tele-operation include hazardous or difficult to access environments, such as radioactive environments ([11,12]), underwater ([13,14]), space ([15,16]), demining ([17,18]), military, medical operations when a specialist is not locally available ([19,20]), etc.

Historically, *tele-manipulation* has ancient roots [21], and modern remote electric motor teleoperation starts with the pioneering work of Goertz and his team in the 50's [22]. Since then, a considerable amount of research in the field has taken place ([23,24]), and one of the centrally-targeted problems was that of compensating for the effects of delay; however, most systems rely on unnatural controllers, such as joysticks [25], which generally require considerable operator training for controlling multi-DoF robots, and which however remains quite cumbersome, without achieving intuitive naturalness of control. Some cases of more natural forms of control do exist; for example a demonstration of the benefits of using human natural arm movement for controlling an excavator [26]. In that paper, the authors use a combination of orientation sensor, rotary encoder, and inclinometer to read the human arm and hand movement and transmit the data wirelessly, in order to control an excavator.

Towards *more natural tele-operation*, one possibility is to try to use motion capture systems that capture a model of points on the human body in real time. Such systems are usually based either on piezo or potentionemeter-equipped suits, or on optical and computer-vision based approaches. Regarding the important problem of correspondence choice between imitator and imitated (robot and human in our case), the reader is primarily referred to the extensive analysis in [27], as well as to [28]. In earlier work, we had utilized real-time optical motion capture, for easy and intuitive tele-operation of an industrial arm, which effectively performs real-time motor imitation of human arm movements, towards completing pre-specified tasks [29], and had provided a novel task-based evaluation framework for such cases.

Moving more specifically towards *natural teleoperation of humanoids* through human-movement imitation, a classic example is the optical motion-capture control of arm movements for the Geminoid android robot [30]. Furthermore, more recently exciting demos of real-time arm and feet movement imitation for the robot Mahru were given [31].

Regarding the possible spectrum between autonomy and continuous direct teleoperation, there exist a number of variations of adjustable [32] and sliding autonomy. For example, in [33], the authors distinguish between System-Initiative Sliding Autonomy (SISA), and Mixed-Initiative Sliding Autonomy (MISA): "SISA allows the operator to intervene only when asked to do so by the autonomous system; while in MISA, the human can also intervene at any time of his own volition".

There are several important *psychological aspects* involved in robotic telepresence. Choice and availability of appropriate sensory feedback to the operator is a primary concern towards effective control and situational awareness; and apart from visual and auditory feedback, if telemanipulation of objects is required, haptic feedback can be quite important. Recently, an interesting body of work has arisen regarding the "Body transfer illusion" phenomenon ([4,34]), i.e. the illusion of owning an entire body which is not the biological physical body of the person experiencing the illusion, and which could be beneficial for the case of telepresence, for example because in such a case interesting multi-sensory perception phenomena take place, such as the "Rubber Hand Illusion" ([35,36]). This illusion is a form of induced sensory completion; after appropriate priming, the person experiencing the illusion, is able to "hallucinate" tactile stimulation corresponding to a seen visual stimulus of a hand which is being touched, thus completing the expected multi-sensory percept. Thus, such phenomena could prove useful towards for example alleviating the need for haptic feedback to the operator of the teleoperated robot, as appropriate feedback would effectively be completed by the operator's mind, of course given appropriate priming as well as the corresponding visual feedback. It is also worth noting that there exist important constraints on many other parameters in order to achieve effective telepresence; for example, conversational dialogue timing can be quite crucial in order to achieve engagement in dialogues.

Thus, having presented basic background for teleoperation, sliding autonomy, robotic telepresence and psychological phenomena, let us proceed to the architecture of the actual system.

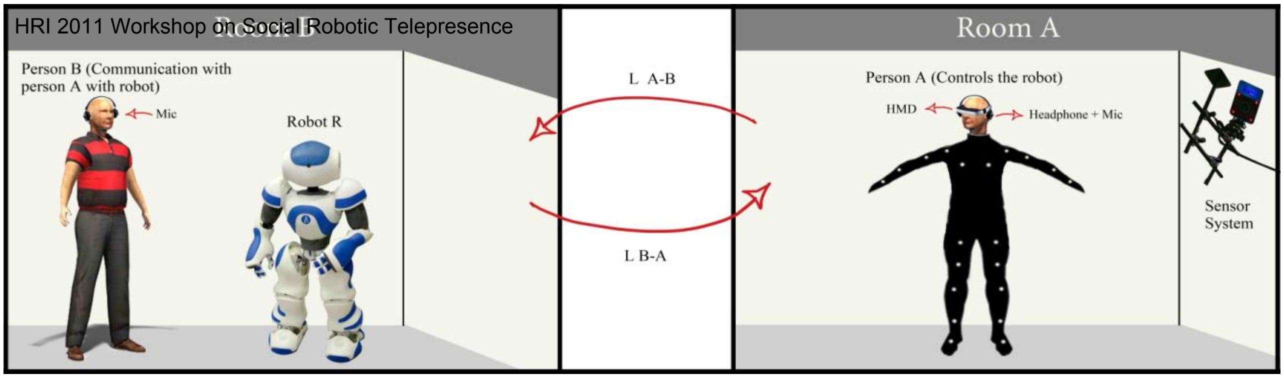

Figure 1: Overall Setting for Android Telepresence

3. SYSTEM ARCHITECTURE

In this section, we present the overall setting of android telepresence, then proceed with a set of requirements, and then present the actual design choices and implementation.

3.1 The overall setting

As we can see from figure 1: Let us suppose the robot R is in a room (Room B), with a person interacting with it (Person B), while in another room (Room A), there is the person who controls the robot (Person A). The body motions of the robot should imitate Person A, and his voice should come out of the robot, so that he will be able to answer back to questions made from Person B. The movement of the body of Person A will be captured by a Sensor System S in Room A, and this data stream, together with his voice, will be sent through a communications link LA-B to the robot R which is in Room B. The voice, video, and other forms of sensory feedback from Room B will be sent to Person A in Room A through another communications link, LB-A, and special sensory coupling devices D (for example a display / speaker device) in Room A will transfer the feedback to the biological sensory system of Person A. Special processing modules PS intervene between the sensory systems S and the robot's actuation and speakers at either end of LA-B, while special processing modules PD drive the sensory coupling devices along LB-A.

3.2 Requirements

A possible set of generic requirements for android telepresence providing a meaningful non-orthogonal decomposition could be:

R1) Operator Body Coverage requirement: be able to copy movements from specific parts of the body of the human operator (Person A), at an adequate quality (in terms of precision and timing). Voice transfer from the operator to the body of the Robot R providing the embodiment can be subsumed for taxonomical compactness in this requirement, too.

R2) Operator Sensory Feedback requirement: be able to provide appropriate sensory feedback to the operator (Person A), as a subset, superset, or correlate of what he would have experienced if he was in the position of the robots, at an adequate quality (in terms of sensory data accuracy as well as timing).

R3) Communicative Effectiveness requirement: be able to provide adequate communicative effectiveness in terms of verbal as well as non-verbal aspects for a specific chosen task, between the operator (Person A) and the Person B, bi-directionally.

R4) Manipulative Effectiveness requirement: be able to provide adequate manipulation and/or mobility capabilities to the remote body for the purpose of a specific chosen task.

3.3 Specific Requirements

The presented generic set is proposed as a starting point, affording alternative decompositions as well as refinements. Moving from the generics to the more specifics of the system, the requirements were translated to the following, after the task was chosen to be: provide brief casual non-technical conversations with possibly more than one co-present interaction partners, with basic gestures and affect display, while being seated.

SR1) Be able to copy arm movements and neck movements, as well as simulate appropriately facial expressions, lip movements, and eye blinking, with adequate precision and timing in order to support the communicative effectiveness requirement R3' below

SR2) Be able to provide color visual feedback through at least one eye of the robot, with VGA-level resolution and with neck motion enabling retargeting, as well as auditory feedback at normal microphone quality.

SR3) Enable communicative effectiveness for a limited set of gestures (handshake, indexicals) as well as affective states (happy, angry, surprised) without fine gradations, as well as for spoken dialogue.

SR4) No manipulative effectiveness required, as the task required neither manipulation of objects nor mobility

3.4 Implementation Choices

The specific requirements SR1 to SR4 imposed constraints upon the available choices for the sensory system S, the links LA-B and LB-A, the sensory coupling devices D, as well as the processing modules PS and PD, given a specific robot embodiment R.

The robot chosen was the Ibn Sina robot [5], whose head contains 28 Hitec servos driven by an SSC-32 controller, while his body and arms have 31 Dynamixel motors driven through a USB-to-Dynamixel converter. A picture of the robot can be seen below:

Figure 2: The Ibn Sina Android Robot

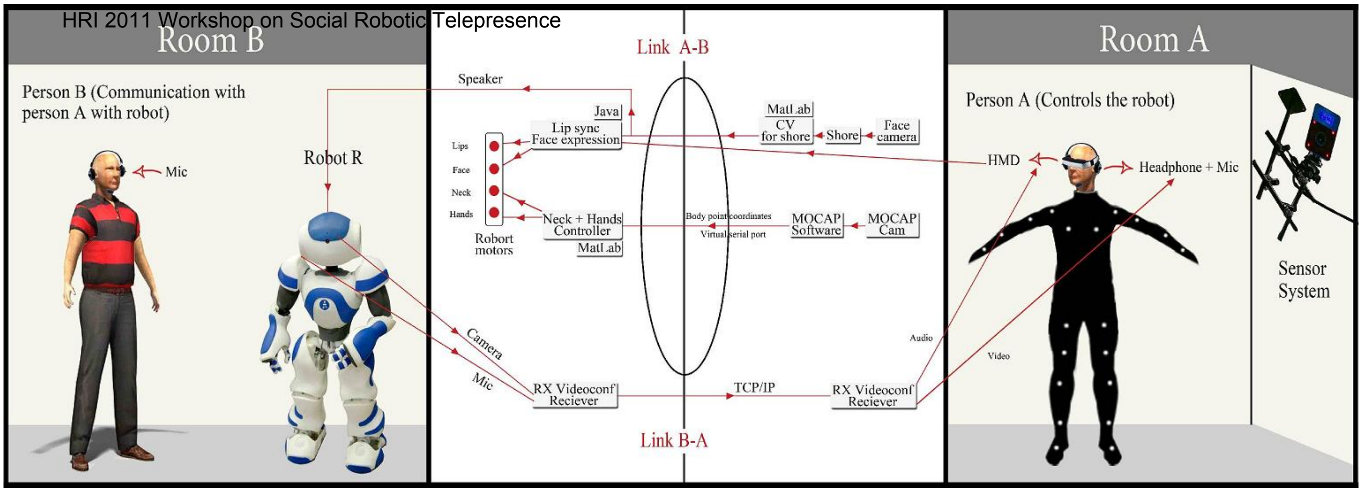

Figure 3: System Architecture Block Diagram

In order to achieve the specific requirements, we made the following design choices, which resulted to the system architecture block diagram shown in figure 3. In more detail:

3.4.1 Sensory System S

A combination of the following devices was chosen:

Motion Capture System: A six-camera motion capture system utilizing cameras of brand standard deviation was used, equipped with infrared LED rings, reflecting on 19 spherical markers placed on a special suit (figures 4 and 5). Later, the mocap system was replaced by a Kinect camera with OpenNI.

Facial Expression camera: a normal webcam was used, feeding the SHORE facial detector / expression analyzer (see 3.4.5).

Microphone: a standard wireless microphone was used

3.4.2 Sensory Coupling Devices D

The Visual as well as Auditory sensory coupling devices were:

Head Mounted Display: A Vuzix HMD with VGA resolution

Headphones: The headphones of the HMD was used

Figure 4: Special Motion Capture Suits (Western/ Custom UAE)

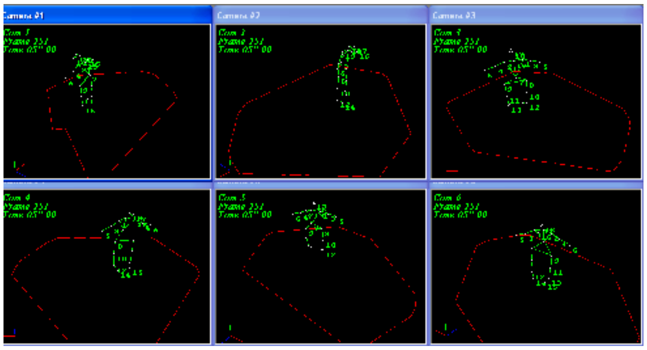

Figure 5: Motion Capture derived model (6 cameras, 19 points)

3.4.3 Processing Modules PS

Arm and Neck Motor Control Module: Special code in a mixture of C++ (interfacing to the motion capture system) and Java was used to feed a virtual serial port in Room A, and a motor control module in Matlab using a Dynamixel control library was used in Room B (figure 6). Out of the 19 points (figure 5), only 8 were utilized: 3 for each arm, and 2 for the neck/head. Instead of using a full inverse kinematics model and/or incorporating adaptation to size differences between the operator's body and the robot, desired angles were calculated on the basis of simple vector trigonometry in order to copy relative orientations irrespective of size differences. The method was found to be adequate for the desired level of gestural communicative effectiveness.

Facial Expression Processing Module: In Room A, the Fraunhofer SHORE facial detector / expression analyzer was used, followed by a custom virtual-camera and Matlab computer-vision-based solution in order to measure the size of the four red affect bars on the display of the program (figure 7), given that we did not have direct access to its API. Initially the blue window of the face detector was tracked, and in a predefined region below it the bars were detected and their length estimated. A four dimensional vector containing contribution weights of four affective states (Angry, Happy, Sad, Surprised) was then sent through the virtual serial port. At the receiving end (Room B), java code that was part of [6], translated the affective vector to desired facial motor positions for 20 out of the 28 facial motors through interpolation between five pre-set archetypal facial expressions for the four affective states plus the neutral state.

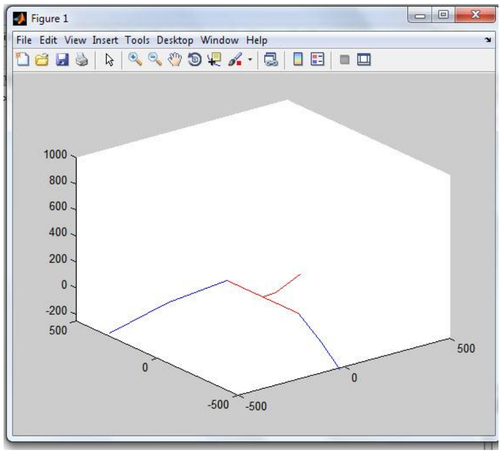

Figure 6: Robot Arm model from Arm Motor Control Module

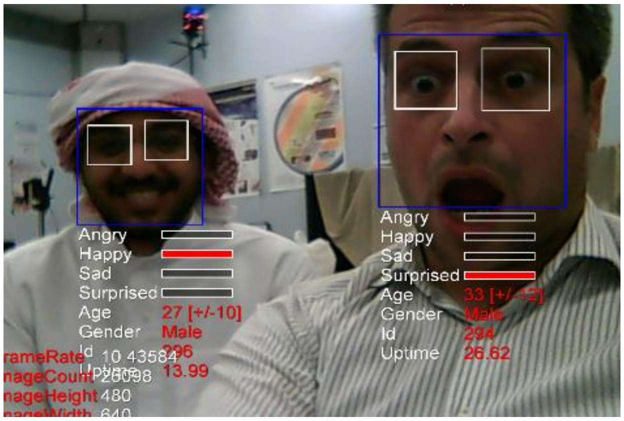

Figure 7: Screenshot from SHORE, fed through virtual camera to the Matlab computer-vision-based bar detector and size estimator

3.4.4 Processing Modules PD

Videoconferencing software (Skype) was used to create the required audiovisual link from the robot's eyes and microphone to the head mounted display and headphones

3.4.5 Link A-B (S to Robot)

A serial-over-ethernet TCP/IP link using the Virtual Serial Port Emulator software (VSPE) was used for the processed motion capture data, a separate virtual serial port was feeding the processed SHORE facial expression analyzer output after the artificial vision property extractor which measured bar sizes from the display of SHORE.

3.4.6 Link B-A (Robot to D)

Videoconferencing software was used to feed the video and audio channels from the robot to the head mounted display and headphones, over an ethernet TCP/IP channel.

3.5 System Demonstrations

The system was created in stages. A demonstration of an early version of arm-only teleoperation can be found in the irmluaeu channel in youtube (figure 8), with the robot and the operator in the same room. A later demo of the complete system, with robot and operator in different rooms, and full equipment, can also be found at the same channel (figure 9).

Figure 8: Early arms-only teleoperation demo (in Youtube)

Figure 9: Android Telepresence system full demo (on Youtube)

4. DISCUSSION

There are various aspects of the system presented that are worth further elaboration. One first interesting point, is concerned with the economical and practical applicability of a wider deployment of operator-side interfaces. In terms of portability, setup time, as well as cost, moving from a motion-capture based interface to the kinect-centered setup represents a big step forward. However, still, the complexity, cost, lack of easy portability, as well as fragility and frequent small malfunctions or problems necessitating expert repair of androids like Ibn Sina is an issue of concern. A second important point is concerned with a question awaiting empirical HRI experimentation: for which applications of telepresence do we really need humanlike androids, as compared to other more robot-like humanoids, which could furthermore be smaller-than-life? Also, many open questions exist regarding translating multiple levels and gradations of task-specific communicative effectiveness (requirement R3) and manipulative effectiveness (R4) into specific operator body coverage (R1) and operator sensory feedback (R2) requirements. Regarding the bitrate requirements of the communication links, the only somewhat more demanding part of the content is the video feed in LB-A. Criticality of delay for the various components of the links is of course an issue, which has partially been studied extensively in traditional tele-operation, but on the other hand its coupling with the induction of the body transfer illusion and other such phenomena remains to be further investigated. Furthermore, another design option is concerned with the benefits of point-to-point versus semantic- or categorical-level approaches to transmitting body configuration data for motor control. For example, in our system facial expression data is transmitted with a categorical-level representation (weights of archetypal affects), while arm movements are transmitted as point data in a skeletal model, and translated to joint angles.

5. NEXT STEPS

We are fine-tuning the dynamics and timing of our system, in order to enable smoother and faster control. Furthermore, a user study with ten experimental subjects is planned, in both operator as well as interaction partner roles, in order to assess through a mixture of subjective as well as more objective measures the performance of our system, for a suitably-chosen communicative task. In the longer-term, we plan to experiment with ways to better integrate our system with Ibn Sina's autonomous mode of operation, to add manipulation capabilities, as well as to perform a field trial in a real-world application scenario.

6. CONCLUSION

In this paper, we started by discussing the main argument providing motivation for our system, i.e. using android telepresence in conjunction with autonomous operation in a sliding autonomy regime in order to make the real-world application of androids as shopping mall robots, receptionists or tutors feasible given the current start of the art of supporting autonomous AI. Such a setting, as we have discussed, provides for a number of important additional benefits, too. Then, after presenting relevant background in a number of related areas, and introducing a set of generic requirements for android telepresence, we presented our telepresence system, whose design was driven by a specific modification of the generic requirements. In our system, the arms, neck, facial expressions, eyes, lips and voice of the Ibn Sina android robot are controlled on the basis of the body movements and voice of a remote operator, while the operator is experiencing the world through the eyes and ears of the robot, fed to a head-mounted display and headphones. The system is the first android telepresence system using very-low cost operator interface equipment (kinect and webcam) while supporting arm, neck, and expression control. Apart from an extensive system description, as well as videos of its actual operation, a discussion as well as a number of important extensions were presented. We hope that the work presented in this paper, in conjunction with the current growing stream of relevant research, will help enable a wider and beneficial deployment of robots in our everyday life.

7. ACKNOWLEDGMENTS

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