The IbnSina Center: An Augmented Reality Theater with Intelligent Robotic and Virtual Characters

Nikolaos Mavridis and David Hanson, *Member, IEEE*

Abstract— **Although numerous early attempts towards the use of robotics in conjunction with virtual characters in order to create augmented reality theater and interactive performances have taken place, the state of the art is still in an initial stage on the pathway towards the full exploitation of the technological as well as creative and artistic potentialities that exist. Here we will present the IbnSina Center, a novel augmented reality interactive theatre installation, named after the famous polymath of the 10th century, known as Avicenna in the West. The installation consists of a ten-meter stage, multiple stage sensors, a screen, a pseudo-3D holograph transparency, and a seating area for the audience. The stage is populated by a custom-designed humanlike humanoid robot (the "IbnSina" robot) and by humans and other entities. The screen and the holograph can display static and moving images, virtual environments as well as online virtual worlds populated by characters, or a windowed / blended mix of the above. The robotic and virtual characters can be autonomous, partially-autonomous, puppetteered, scripted, or real-time-controlled by imitation of human body movements (embodied telepresence). Furthermore, multiple modes of participation of distant humans can be supported: not only through videoconference, but also through control of robots and/or virtual characters. The IbnSina center serves as a platform for multiple purposes: artistic, research as well as educational; and most importantly, the centrality of a progressive character such as IbnSina catalyzes the reconnection of the wider region of the UAE to a past during which scientific inquiry and the arts had flourished; and thus, enables the creation of a future for the region which will emphasize such cultural values.**

I. Introduction

THE IbnSina Center is a novel augmented reality interactive theatre installation, named after the famous polymath of the 10th century, known as Avicenna in the West. The installation consists of a ten-meter stage, multiple stage sensors, a screen, a pseudo-3D holograph transparency, and a seating area for the audience. The stage is populated by a custom-designed humanlike humanoid robot (the "IbnSina" robot) and by humans and other entities. The *purpose* of the IbnSina Center is *tri-fold: art, research,* as well as *education*.

In terms of *art*, the center enables the exploration of multiple novel expressive means and their combinations, enabling physical, robot-mediated as well as virtual character-mediated participation of locally present or remote humans, and interactions with autonomous and semi-autonomous artificially intelligent entities, within an augmented reality environment. In that sense, it considerably extends upon current work in interactive robotic theatre and arts, as we will discuss in the first background section.

In terms of *research*, the center enables hands-on research in a wide number of related areas: humanoid robotics, virtual worlds and characters, robotic tele-presence, and human-robot interaction are just a few among them. The co-presence of a humanoid together with an extensive sensor network for determining the physical situation around it (human body postures, object positions etc), directly next to a life-size projection of virtual worlds and characters, creates a big number of interesting combinations, as we will see in the discussion section.

In terms of *education*, the center enables the creation of exciting hands-on real-world projects for students, as well as the constructive co-existence of students coming from media arts as well as from technical backgrounds.

This paper describes the authors' collaborative work towards the realization of the Ibn Sina center. Nikolaos Mavridis has provided the idea and conceptual design behind the center, has created a monologue script which was used for an animation ("The Dream of IbnSina"), and is leading the software development and the project. David Hanson has designed, crafted and created the Ibn Sina humanlike robot, the main robotic character of the center. The paper starts with a background section, covering interactive robotic theater and arts, and discussing the historical Ibn Sina and his relevance to the region. Then, we provide a description of the theatre, its configuration and its equipment, including a detailed section on the creation and capabilities of the Ibn Sina humanlike robot. Later, we discuss the capabilities of the center, across a number of organizational axis. Finally, we talk about steps taken and future steps, and provide a concluding discussion. It is our hope that the Ibn Sina center will help bring forth the values associated with this historical figure, and thus benefit the region and the world.

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Nikolaos Mavridis is with the Interactive Robots and Media Lab, United Arab Emirates University, Al Ain, Abu Dhabi, phone: +971-50-1375283; fax: +971-3-7672018; e-mail: irmluaeu@gmail.com.

David Hanson is with Hanson Robotics, Dallas, TX, USA (e-mail: david@hansonrobotics.com).

II. BACKGROUND

A. Interactive Robotic Theater and Arts

As robots and agents grow more socially capable and intelligent, these technologies promise to realize intelligent theatrical characters that get to know the user increasingly well, form relationships with people, and ever better satisfy the human desire for characters that appear alive and aware. Such intelligent characters, growing more humanlike in affect and interactivity, in effect, humanizes our human-computer interfaces. We contend that the impact of such intelligent character technology may extend beyond theater and arts, to serve more generally as increasingly intuitive interfaces for computers.

Historically, developers of robots and intelligent agents have focused on mechanical-utility applications, for example: physical caretaking, lawn-mowing, unmanned vehicles, and factory work [1], [2]. On those occasions that theater and arts have been considered as an application for robotics and/or agents, the value is often regarded to be vague or frivolous—of mere cultural or entertainment value [3]. However, this paper adopts the philosophy that theater and arts can provide techniques that make robots much more human-accessible than engineering techniques alone, resulting in improved human robot interaction in general.

Such artistic creative techniques are intuitive, involving visual and narrative creative problem-solving methods, most of which science does not yet understand, and so aren't formalized or empirically tested [4]. And yet these techniques work, as is demonstrated by the numerous artistic works that are so engaging to humans. This "black box" problem solving for aesthetics and narrative can be a powerful approach which may result in engaging useful results extending beyond the arts, improving therapy, education, customer service, and other applications.

As robotics technologies are applied in works of theater and art, the authors contend that robotic theater may grow disruptive to 21st century culture and industry. The precise impact of intelligent character machines is difficult to predict, but we speculate that it if it succeeds in deeply engaging users over long periods of time, they will become the backbone of interactive cinema and narrative. As characters come to life in our world, with their own motives, intentions, and ability to adapt, they will be ever more woven into society. Art and life no longer will just mirror; the glass dissolves and the worlds mingle.

Already, there have been early works in this effort, with encouraging early results. The entertainment, toy, and videogame industries have dramatically demonstrated that robotics can enthrall the public, with bold economic performance and market demand . The use of animatronics in theme parks and movies have proven industries from the 1960s to the present, whereas multi-$billion/year markets have emerged for robotics in toys [5] and intelligent characters in games. The Pirates of the Caribbean at Disneyland and the Massive Software agents of the Lord of the Rings are cultural icons, and each is driven by robotics and A.I. [6]. Robotics has found its way into influential fine art as well, with examples including the chat-bot animatronics of Ken Feingold, the destructive automata of SRL, and the animatronic works of Chico MacMurtrie and Paul McCarthy, [7].

Additionally, social robotics are sometimes motivated as works of art and fiction. The influential social robotics scientist Cynthia Breazeal cited artistic motivations [8] and collaborated with animatronics artists from Stan Winston studios when developing Leonardo [9]. The domains of social robotics and cognitive science overlap at times, which offers the opportunity to study the perception and cognition of social exchange, and simulated social exchange as exhibited in the character arts.

The robots of co-author David Hanson also bring together engineering and an artistic motivation, a history as an animatronics designer for Disney, a background as a conceptual artist, and a background engineering social robotic hardware and software, to create character robots as works of art. In previous robots, Hanson and collaborators combined machine intelligence and perception components with facial expression robotic hardware and a novel porous skin rubber material called Frubber, to realize conversational characters that included the Android Portrait of Phillip K Dick [10], the walking Hubo-Einstein , and the character Zeno [11].

Finally, it is worth noticing some further important existing work towards directions that are important in our theatre, as we shall see. Interactive robots with situated language abilities include [12] – and language about the present and the past of the situation is important for our purpose. Moving from autonomy to tele-operation - a classic example of humanoid robotic telepresence is presented in [13], where a full-body replica of Dr. Hiroshi Ishiguro is being exploited as a "telecommunication medium with a Human-like Presence". Furthermore, an example of a real-world public robot-to-robot performance is given in [14]; and important results regarding people's reactions during such a field experiment at a train station can be found at [15].

B. IbnSina, the 10th Century Polymath

A "polymath", a word deriving from the Greek "πολυμαθής" is a person with a broad range of learning and scholarship – a notion very similar to "Homo Universalis" or "Renaissance Man". Few historical figures qualify for this title; the most notable and well-known in the West probably being Leonardo da Vinci. In the East, the two most well known such figures are Ibn Sina (known as Avicenna in the West) and Ibn Rushd (Averroes).

Ibn Sina (Abu Ali Ibn Sina, 980-1037) was the foremost philosopher and physician of his times. He was also an astronomer, chemist, geologist, logician, mathematician, poet, psychologist, scientist, and teacher. He wrote more than 450 treatises on a wide range of subjects, and his "Canon of Medicine" [16] was a standard medical text at many medieval universities. His work built upon the knowledge of the ancient Greeks (Galen's medicine and Aristotle's metaphysics), as well as upon ancient Persian, Mesopotamian, and Indian works and ideas. He made numerous important contributions to all the fields that he excelled in, and lived an adventurous life with numerous transformations and turning points, making him ideal as a starting point to artistically build upon.

C. Relevance of Ibn Sina to the UAE

Ibn Sina is well known in the middle east, and especially in greater Persia and the Gulf region, where he is being perceived as one of the most important figures of the cultural heritage of the area. In the United Arab Emirates, his name is familiar in multiple everyday ways; there is even a chain of pharmacies named after him.

The United Arab Emirates, is a fast-developing country, which has already achieved many world firsts in impressive projects, including the building of the world's tallest tower (the burj Dubai). Furthermore, it is quite an interesting country from a social point of view, as it consists of a unique multicultural blend, and as it is currently quickly evolving its cultural identity, and acting as a prototype for numerous nations of the region.

Given this on-going process of identity formation and the specifics of the UAE and our student population, the decision was made to select Ibn Sina as the central figure of this center, and as the first robot of it. A progressive character such as IbnSina can catalyze the reconnection of the wider region of the UAE to a past during which scientific inquiry and the arts flourished; and thus, can help enable the creation of a future which will emphasize such cultural values, and enable it to provide a distinctive contribution to humanity in the 21st century.

III. The Installation

The installation consists of a ten-meter stage, multiple stage sensors, a screen, a pseudo-3D holograph transparency, and a seating area for the audience. The stage is populated by a custom-designed humanlike humanoid robot (the "IbnSina" robot) and by humans and other entities. In more detail:

A. The Room

The IbnSina Center is located at the third floor central core area of the new building of the College of IT of UAEU, which is a cone-section-shaped room, with a lower diameter of roughly 14 meters (see Figure 1 below), connected with two bridges to the rest of the building. The room has no windows, and its surface has been covered with audio damping materials to avoid echo.

B. The Stage, Seating Area, and Control Area

The performance stage has the shape of a circular arc, containing roughly one fourth of the circumference of the room, and having a width of 9.4 m, a maximum depth of 1.82 m, and a height of 1m. A depth extension of 1m was later added to the stage, as well as a staircase enabling easy entry of humans and robots. A motor-controlled curtain can cover the stage. The seating area enables the accommodation of an audience of twenty, and is easily reconfigurable. Behind the seating area lies the control desk, hosting equipment as well as two operators.

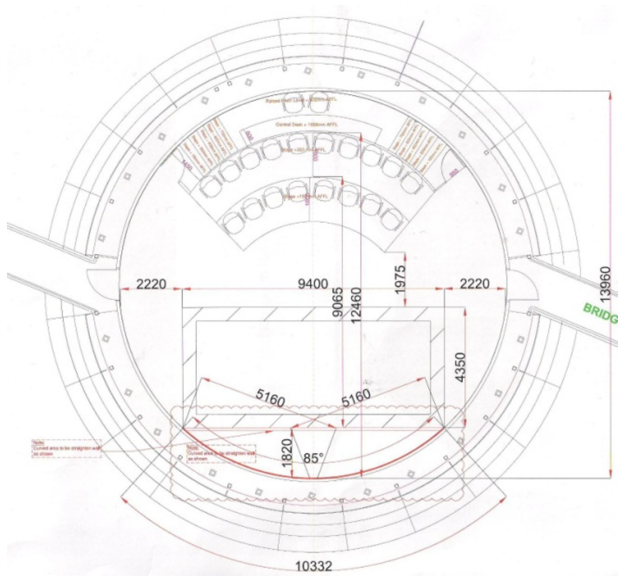

Fig. 1. Floor plan of the Ibn Sina center

C. The Screen, the Hologram, and the Video System

The screen covers the whole of the back of the stage, and has the shape of a cylindrical sector, with a total length of 10.3m, and a height of 3m. The hologram film is mounted at an angle and in front of the stage, and is held by a metallic truss. Two 10K Panasonic projectors illuminate the hologram film (left and right sections), while an 8K Christies projector illuminates the cylindrical screen behind the stage. The projectors are mounted on a truss above and in front of the stage. The video system feeding the projectors consists of four personal computers: one master (production computer) and three slaves (display computers), with one slave per projector. The software package Watchout [17] provides the basis for multi-display production and presentation functionality.

D. Room Lights and Audio System

Small blue lights serve as wall lights, floor lights, audience seating lights, as well as basic stage lights, all of which are controllable by the control desk. Two halogen lamps can also flood the room if required. No special theatre lighting system was installed yet. The audio system consisits of DI boxes and three two-channel amplifiers, connected to a 5+1 stage surround system. There are also two extra control area monitor speakers.

E. The Stage Sensors

A six-camera MotionCaptor [18] motion capture system has been mounted above the stage, enabling two-actor motion capture in an area of roughly 4 x 3 meters. Furthermore, polhemus liberty latus [19] wireless position and pose sensors can be mounted on moveable objects. Finally, wireless cybergloves [20] are also available for the human actors.

F. The Robot

The IbnSina robot is seated on a moveable chair and placed on the stage. The robot has a very humanlike appearance (see Figure 2 below), with extensive facial expression and hand gesture capabilities. Currently, with a wireless-enabled laptop under the chair, only a power cord is needed for its operation, which can also be eliminated by an under-the-chair UPS system if long-term operation is not needed. More details about the creation, the internals, and the capabilities of the robot follow.

Fig. 2. The Ibn Sina Humanlike Robot

IV. THE IBNSINA HUMANLIKE ROBOT

The process for the robotic character portrait of Ibn Sina combines a host of classic artistic techniques with current robotics practices. The portrait began as a series of sketches, which served as inspiration for a clay sculpture, rendered by hand in the classical style.

This portrait used the existing sculptures and drawings of Ibn Sina as reference, but these deviate from one another significantly, which makes a definitive portrait impossible. The portrait fused characteristics from each of the great portraits of the man, in turn resulting in a new interpretation of the man.

From there, the sculpture is molded, and a skull is derived from the skin form using a reverse-forensic reconstruction process. Anatomically accurate tissue thickness readings are used as reference to ensure that robot's skin s anatomically correct and hence, expressive.

This skull form is used both as the core for the skin molding process, and is used to generate the mechanical frame for the robotic skin. This is achieved by laser scanning the skull form and the sculpture to use in Solidworks computer aided design (CAD), and custom engineering the facial expression mechanisms to the new sculpted face.

The design of expressions and muscle action is a fusion of engineering and art. The engineering involves the replication of the action of 48 major muscles in the face, from frontalis, to mentalis, from orbicularis to zygomaticus, and all muscles in between. The mechanics of these muscles are replicated by linkages that pull along vectors that replicate the natural muscle action, and which link to tiny servos. The linkages distribute the force into the skin by connecting to flexible elastomer-fiber composite anchors, which simulate the fascia and connective tissues in the facial expression system in the naturally occurring face. The soft-body deformations must be calculated and designed, and natural facial actions must be considered as well. However, the end affect of each muscle action is considered as a work of sculpture. The expressions that are achieved via the mechanical system must look as good as though it was sculpted by a master sculptor. This requires the roboticist to simultaneously design a novel engineered system and a work of art, as an integrated system.

To achieve humanlike expressivity in the face, the author used a porous elastomer invented by Hanson called Frubber [4]. This material, being a fluid-filled porous elastomer, better matches the physics in the human facial soft tissues than do conventional elastomer materials [24]. Thus the resulting facial expressions crease and wrinkle better, and require considerably less force to actuate. This allows a full set of simulated facial muscles to be included in the special envelope of the robotic head.

In addition to facial expressions, the Ibn Sina robot included robotic neck action and arms. The arms and neck were actuated using Dynamixel/Maxon motors. The arms contain 14 degrees of freedom each, the neck includes 3, and the face contains 28, for a total of 59 degrees of freedom. The robot contains Sony CCD imaging embedded in the realistic robotic eye, custom fabricated by Hanson. This sensor provides 640 x 480 color imaging with .2 lux sensitivity, and a high-contrast imaging ability relative to CMOS imagers.

The Ibn Sina hardware allows a high fidelity simulation of a full range of human facial expressions, and the majority of gestural function of human neck and arms. The figure has been decorated with clothing that historically resembles garb of the time of Ibn Sina, and with facial hair and skin coloration that mimics the appearance of Ibn Sina as closely as possible.

The theatrical effect of the uncannily realistic human is considered both a work of artistic portraiture and an act of perceptual/cognitive play, proto-science. But as Robotics grows more intelligent, it has the potential to bring characters to life in unprecedented ways, and new software techniques can control aesthetic experiences to create dramatic otherworldly experiences. Just as cinema did for the 20th century, robotics promises bold, disruptive arts for the twenty first century.

V. Capabilities of the IbnSina Center

Here we will attempt to organize and taxonomize the capabilities offered by the centered, through a set of axis along which the entities (humans, robots, virtual characters etc.) participating in the performance can be placed. This taxonomical system extends upon Milgram's reality-virtuality continuum [21], and accounts for both the *nature* as well as the *appearance*, of both the *body* as well as the *driving intelligence* of the performing entities (four dimensions). Also, it contains a further dimension accounting for the level of *autonomy* of the entity. This uni-dimensional view of levels of autonomy is simpler than the axis-of-autonomy view of [22], however is perfectly adequate for our present taxonomical purpose. In more detail, the five axis of our taxonomy follow:

The first axis (A1) is that of the *nature of the body* of the entities present in the performance, which can be: physical (on stage), or virtual (projected to the screen and/or hologram). Entities of a physical nature can be biological (humans / animals / plants), natural (inanimate; such as stones, soil), as well as artifactual (man-made; robots, devices, furniture).

The second axis (A2) is that *of the appearance of the body* of the entities, which can be: human, animal, cartoon-like, robot-like etc., where of course the latter categories are shaped by cultural expectations of the appearance of such body. Appearance here refers to both form (static) as well as movement (dynamic).

The third axis (A3) is that of the *nature of the driving intelligence* behind the entities: this can be human / biological or artificial or even mixed.

The fourth axis (A4) is that of the *appearance of the driving intelligence* behind the entities, and this might well differ from A3: for example, a human operator might be controlling the movements of a virtual cat in real time, making her appear as having a cat-like intelligence.

Finally, the fifth axis (A5), accounts for the level of *autonomy* of the entities: they can be autonomous, partially autonomous (switching between autonomous and non-autonomous modes), puppeteered (macro-managed or micro-managed), or at the other extreme bound-to-mirror (for example, robotic telepresence through motion capture [12] or simple video mirroring from a remote camera).

Across these five taxonomical axis, many interesting combinations and configurations can arise. A simple case illustrative example follows. A scene in an interactive performance involved the following entities:

I) An AI-driven virtual humanlike character
(A1: body nature - virtual, body appearance - human, A2: intelligence nature - artificial, intelligence appearance - human, A3: autonomous)

II) A human-pupeteered virtual character of a dog
(A1: body nature - virtual, body appearance - biological, A2: intelligence nature - human, intelligence appearance – dog, A3: puppeteered)

III) A human present on stage, free to act
(A1: body nature – physical biological, body appearance - human, A2: intelligence nature: human, intelligence appearance: human, A3: autonomous)

IV) A humanlike robot bound-to-mirror a remote human
(A1: body nature – physical artifactual, body appearance: human, A2: intelligence nature: human, intelligence appearance: human, A3: bound-to-mirror)

V) A physical table
(A1: body nature - physical artifactual, body apperance: table, A2: no intelligence, A3: non-autonomous)

The introduction of various forms of sensors on stage, as well as the network connectivity and the co-presence of humans, objects, projected items and robots thus enables a wide variety of interactions and connections within the vast space generated by all of the above possibilities: The screen and the holograph can display static and moving images, virtual environments as well as online virtual worlds populated by characters, or a windowed / blended mix of the above. The robotic and viratual characters can be autonomous, partially-autonomous, puppeteered, scripted, or real-time-controlled by imitation of human body movements (embodied telepresence). Furthermore, multiple modes of participation of distant humans can be supported: not only through videoconference, but also through control of robots and/or virtual characters. And all of these can be neatly taxonomized within the above generative framework.

Fig. 3. The IbnSina Virtual Character

VI. CURRENT AND NEXT STEPS

The Ibn Sina center has now reached early operation status, less than one year after work on it had started, and less than two years from its initial conception. In more detail, so far:

1) Equipment was designed / selected, created / ordered, and installed (robot, sensors systems etc.)
2) The room of the theatre was designed, constructed, and delivered, including projection, control and AV equip.
3) A script for a monologue ("The Dream of Ibn Sina") was written, and part of it was turned into an animation containing virtual characters and graphics, with separate layers for the hologram and screen (see Fig.3)
4) The robot was designed, built, and testing concluded.

Currently, the following steps are under way:

5) Software for more flexible robot control, customization of existing character engine software, adaptation of modules from other of our interactive robots projects (such as FaceBots [23]) is underway
6) Motion training / Embodied Telepresence software is being created for copying mocap data to the robot in pre-recorded or real-time settings
7) Creation of an IPC-accessible unified software interface for all the equipment of the center, enabling easier and more extensive interoperability

Finally, in the near future, a phase of team expansion and artistic content creation will be entered, acting as a preparation for a major annual performance event.

VII. CONCLUSION

In this paper we have presented the IbnSina Center, a novel augmented reality interactive theatre installation, named after the famous polymath of the 10th century. We started by introducing the *tri-fold purpose* of the center, and by providing relevant *background*: in interactive robotic theater and arts, as well as in the historical Ibn Sina and his current relevance to the region. Later, we discussed the *installation*: the stage, the sensors, the screen and holograph, the audiovisual systems, as well as the *humanlike robot*. The extensive *capabilities* of the center for creating interactions among multiple entities with various bodies, forms, types of driving intelligence and degrees of autonomy were then discussed, and a taxonomical framework was provided. Then, we discussed *steps* taken, steps currently underway, and steps to be taken in the near future.

In conclusion, the IbnSina center serves as a platform for multiple purposes: artistic, research as well as educational; and exhibits numerous novelties. Most importantly, the centrality of a progressive character such as IbnSina catalyzes the reconnection of the wider region of the UAE to a past during which scientific inquiry and the arts had flourished; and thus, enables the creation of a future for the region which will emphasize such cultural values, and which will hopefully help towards the creation of a better future for the world.

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