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A Midsummer Night's Dream (with flying robots)

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Abstract
Seven flying robot "fairies" joined human actors in the Texas A&M production of William Shakespeare's *A Midsummer Night's Dream*. The production was a collaboration between the departments of Computer Science and Engineering, Electrical and Computer Engineering, and Theater Arts. The collaboration was motivated by two assertions. First, that the performing arts have principles for creating believable agents that will transfer to robots. Second, the theater is a natural testbed for evaluating the response of untrained human groups (both actors and the audience) to robots interacting with humans in shared spaces, i.e., were believable agents created? The production used two types of unmanned aerial vehicles, an AirRobot 100-b quadrotor platform about the size of a large pizza pan, and six E-flite Blade MCX palm-sized toy helicopters. The robots were used as alter egos for fairies in the play; the robots did not replace any actors, instead they were paired with them. The insertion of robots into the production was not widely advertised so the audience was the typical theatergoing demographic, not one consisting of people solely interested technology. The use of radio-controlled unmanned aerial vehicles provides insights into what types of autonomy are needed to create appropriate affective interactions with untrained human groups. The observations from the four weeks of practice and eight performances contribute (1) a taxonomy and methods for creating affect exchanges between robots and untrained human groups, (2) the importance of improvisation within robot theater, (3) insights into how untrained human groups form expectations about robots, and (4) awareness of the importance of safety and reliability as a design constraint for public engagement with robot platforms. The taxonomy captures that apparent affect can be created without explicit affective behaviors by the robot, but requires talented actors to convey the situation or express reactions. The audience's response to robot crashes was a function of whether they had the opportunity to observe how the actors reacted to robot crashes on stage, suggesting that pre-existing expectations must be taken into account in the design of autonomy. Furthermore, it appears that the public expect robots to be more reliable (an expectation of consumer product hardening) and safe (an expectation from product liability) than the current capabilities and this may be a major challenge or even legal barrier for introducing robots into shared public spaces. These contributions are expected to inform design strategies for increasing public engagement with robot platforms through affect, and shows the value of arts-based approaches to public encounters with robots both for generating design strategies and for evaluation.

Keywords: Robot theater, Robot affect, Human-robot interaction, Public performance, Unmanned aerial vehicles

1 Introduction

Seven flying robot "fairies" joined human actors in the Texas A&M production of William Shakespeare's *A Midsummer Night's Dream*. The November 2009 production grew out of a January 2009 meeting between members of the Computer Science and Engineering (Murphy) and Performing Arts (Casey, Hopper, and Morris) departments to discuss how to expose roboticists to the principles in creating believable agents.

The theater arts offer many advantages for studying human-robot interaction in public encounters. Theater has an experience base of creating believable agency and predicting how "untrained" observers (the audience) will interpret agents' intent, but this base is not codified in a form suitable for computational systems. It is a domain where success is defined by large numbers of the general population observing agents (attendance) and by the believability of the agents (as measured by reviews and audience feedback) working together in a shared space. Breazeal et al. (2003) argue that the theater is a suitable test domain for social robots because the interaction is bounded by the script, the environment is constrained and can be engineered to support robots, and the robots must be convincing and compelling.

The introduction of the robots, one pizza-sized AirRobot 100-b Quad-rotor and six E-flite palm-sized toy helicopters, did not alter the play and were not limited to a single scene (as with the recent production of *Phantom of the Opera* (Lin et al. 2009)). The robots did not subsume any roles, yet the integration of the robots into the narrative of the play made the robots more than props, in contrast to the robotic technology used in *Cymbeline* (McCoy 2008; Ruggiero 2008). More importantly, the robots were inserted into an existing play written about humans rather than a play written specifically for robots (cf., Werger 1998) or about human-robot interaction. By being supporting elements in a "human" play, the robots provide insights into believable human-robot interaction.

The plot of *A Midsummer Night's Dream* can be summarized as follows. In the days leading up to the marriage of Duke Theseus of Athens and Queen Hippolyta of the Amazons, love-struck Athenian teenagers Lysander and Hermia run away together through the Athens forest pursued by Demetrius, who loves Hermia, and Demetrius is pursued by Helena, who loves him. Meanwhile, a blue-collar community theater troupe meets in the same forest to rehearse the play they are performing in honor of the wedding of Theseus and Hippolyta. Unfortunately for all, this forest is ruled by an arguing Fairy King and Queen. The Fairy King decides to get back at his queen by placing a magic spell on her, and, after encountering the teenagers and workers in his forest, he decides to have some fun placing magic spells on most of them, too. When the spells are finally released by the Fairy King, harmony and love are restored to all and the wedding and play happen as planned. The director (Hopper) began envisioning the forest as a fairy "otherworld" where human fairies shape-shift into robot fairies, costumes incorporate high-tech elements (LEDs, light ribbons, fiber optic fibers, metallic jewelry), and fairy movements generate evocative sounds, similar to the sound shifts in the humming of a light saber in Star Wars.

The concept of using small unmanned aerial systems as fairies was a part of the production from its inception. When the production officially began in the Fall semester, the three lead engineering professors (Murphy and Shell from Computer Science and Engineering and Zourntos from Electrical and Computer Engineering) attended all the production meetings. The professors, operators, and robots participated in all development and dress rehearsals. The choice of robot platforms, the decision for teleoperation, the behaviors and staging, and all aspects were collaborative. As a result, the production provides a solid foundation for understanding how robots can generate believable agency.

The play ran for eight performances and one preview over two weeks and was entirely sold-out during the second week. The presence of robots in the play was not advertised, though the announcement for the local newspaper did mention robots would be involved. In general, the audience was the typical theater-goer and were not disproportionately technophiles. Thus the audiences represented "untrained observers" who had little or no knowledge of, or previous interaction with, robots and were there to see a Shakespearean play. The audience reaction to the play was outstanding as evidenced by the sold-out shows, the review in the university newspaper praised the production and seamless incorporation of the robots, and the production was covered by Wired and other online news outlets which circulated video clips.

This article describes the flying robots and their roles in the play, focusing on identifying the human-robot interaction mechanisms employed that generated the attribution of affect by observers as a first step in formalizing how humans perceive affect in non-humanoid robots. It begins by surveying the previous and related work in affective robotics, identifying the few known instances of mobile robots in theater productions. The article next describes the two types of robots used as fairies, followed by a description of each scene involving robots. The audience and actor reaction to the robots is then captured, culminating in a discussion in which we provide four insights gained from our experience with this production: (1) codifying the mechanisms used for generating affect in the form of a preliminary taxonomy; (2) a new understanding of the role of actor improvisation in robotic theater; (3) an explanation of observed expectation forming processes; and (4) observations on the importance of safety and reliability.

2 Previous and related work

The staging of *A Midsummer Night's Dream* appears to be the first integration of mobile robots, either ground or aerial, into a complete production of an existing play. The inclusion of robots was motivated by an intent to explore affect in nonanthropomorphic robots versus portraying socio-political themes or demonstrating improvements to humanoid robots. The production also differs in the conclusions about the role of improvisation. As with many of the robot theater systems surveyed, the aerial vehicles in *A Midsummer Night's Dream* were operated by humans.

Ground robots have participated in portions of *The Phantom of the Opera* but not the complete play (Lin et al. 2009). Robotic technology such as a large printer was used in a recent production of Shakespeare's *Cymbeline* but actual mobile robots do not appear to have been present (McCoy 2008; Ruggiero 2008). As such, *A Midsummer Night's Dream* is the first use of robots alongside with human actors in a play that is part of the theater canon. The staging of *A Midsummer Night's Dream* is also unusual in that the inclusion of robots was not widely advertised or used to attract the audience; publicity about the robots came from a review of the play by the student newspaper (Gerhart 2009) followed by national press (Squatriglia 2009) after the play ended. Thus the audience for the performances were primarily "normal" theatergoers expecting a play by Shakespeare.

Since the 1990's, ground robots have been used in plays written for robots (e.g. Werger 1998) or for improvisational theater (e.g., Bruce et al. 2000). Bruce et al. (2000) and later Breazeal et al. (2003) compare the challenges of using robots in a scripted play versus improvisation, with Bruce et al. (2000) arguing that improvisational drama is superior in terms of audience satisfaction and understanding dramatic structure for human-robot interaction. The experience with *A Midsummer Night's Dream* provides a counterpoint to Bruce et al. (2000) and Breazeal et al. (2003); a play performance by robots requires understanding the context of a particular evening's performance, changes in lines, pacing with respect to the particular audience, changes in lighting speed, failures of technological elements, etc. Improvisation occurs even in a scripted play performed by only human actors, as it is not an entirely predictable sequence of events. As described in Sect. 4.8, the inclusion of robots led to minor improvisations within the context of the play to compensate for variations in robot behavior and crashes, illustrating how the inclusion of robots is richer than mere playback of fixed patterns. Likewise Sect. 5 describes the audience reaction which clearly found the staging to be satisfying as a performance of a Shakespeare play.

The motivation for incorporating robots or writing a play specifically for robots generally falls into three categories: to explore socio-political themes in accepting robots into society (which are too numerous to cite here, but begin with Karel Čapek's R.U.R.), affect and expressiveness of robots (Lin et al. 2009; Mavridis and Hanson 2009a, 2009b; Perkowski et al. 2005), experimental aesthetics (Apostolos et al. 1996; Dompierre and Laurendeau 2006; Iida et al. 2008;Mavridis and Hanson 2009a, 2009b; Ohya et al. 1996; Paricio García and Moreno Aróstegui 2007), or some combination. The majority of productions exploring affect and expressiveness of robots have concentrated on improving the physical expressiveness of humanoid robots (Lin et al. 2009; Mavridis and Hanson 2009a; Perkowski et al. 2005), on creating the sensing needed for awareness (Lin et al. 2009; Perkowski et al. 2005), or computational structures (Burke et al. 2006;Mavridis and Hanson 2009a, 2009b;Wallis et al. 2010). The production of *A Midsummer Night's Dream* was motivated by the desire to understand affect and expressiveness of non-humanoid robots, using commercially available robots designed for flight stability with limited degrees of freedom.

The robots used in *A Midsummer Night's Dream* were controlled by human operators, placing this within the puppetry category defined by Beaumont (1958) and Tillis (1992). As noted in Demers and Horakova (2008), puppets and robot performers are both inert entities called on to perform in front of an audience. However, we believe that this distinction is insignificant for this article as the purpose of the reported research is to better understand affect and expressiveness as the first step towards capturing it with autonomous behaviors. Of the robotic performance systems, only Breazeal et al. (2003), Lin et al. (2009), Perkowski et al. (2005) appear to use fully autonomous robot actors, while Iida et al. (2008) had the audiences and actors interact essentially through teleoperation, Mavridis and Hanson (2009a, 2009b), Paricio García and Moreno Aróstegui (2007) support both autonomous and teleoperation, while Ohya et al. (1996) and Goto and Yamasaki (2007) captures human performers' movements and translate them into robot or avatar actions. The teleoperation of the robots in *A Midsummer Night's Dream* is somewhat similar to the participatory theater described in Ambach and Repenning (1996), where an artist painted in conjunction with autonomous robots.

3 Robots

We employed two types of micro unmanned aerial vehicles. Both types were teleoperated by volunteers positioned in seating aisles and exit corridors so as to maintain constant line-of-sight with the robot. The two types of robot were different enough in size, payload, controllability, and sound to provide quite distinct costuming, staging, and flying challenges.

3.1 AirRobot 100-b Quad-Rotor

The AirRobot 100-b is a micro (1 m diameter) unmanned aerial vehicle equipped with autonomous flight and navigation capabilities and modular 200 g payload. The robot was designed with outdoor reconnaissance and surveillance tasks in mind. Four separately driven battery-powered electric motors turn four fixed pitch rotors positioned near the corners of the robot; this arrangement permits vertical take-off and landing, and a stable hover. Typically these robots are flown hundreds of feet above the ground, the extremely confined indoor spaces and close proximity to people meant that autonomous flight was infeasible. The low ceiling and angled shape of stairwell posed a particular challenge in launching and landing the device, requiring the pilot to demonstrate considerable skill.

The platform proved to be stable, reliable, and adequately controllable for the performance. The natural stabilization of roll and pitch by the device meant that synchronization to music in dancing scenes was mainly produced by moving the position of the robot back and forth which creating an undulating effect with concomitant variation in the roll and pitch.

While the robot's size and payload permitted several possibilities in developing the costume, its shape and need for free space around the rotors resulted in a Jellyfish inspired costume. Figure 1 gives an impression of the quad-rotor robot and the effect produced by the electroluminescent wire wrapped around the carbon-fiber frame.

Although considered silent by unmanned aerial vehicle standards, we found it to be louder than ideal for the theatrical setting.

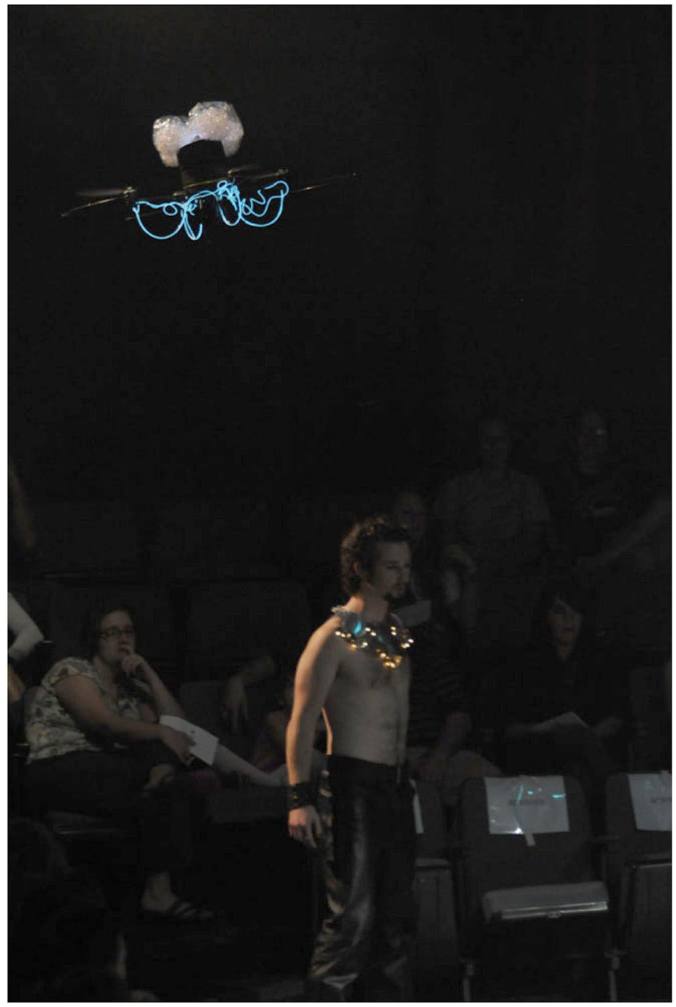

Figure 1. Fairy King Oberon with costumed Quad-Rotor. The robot serves as his fairy minion, hovering overhead, and exiting in response to his commands.

3.2 EFlite micro-blade MCX

The second type of robot used was a miniature (20 g) radio-controlled helicopter produced by EFlite for hobbyist and specifically intended for indoor flight. The electrically powered helicopter (we term micro-heli) uses two adjustable pitch contra-rotating 19 cm blades that enable it to do without a tail rotor. Although at most six were used concurrently, from rehearsal to the final production a total of 22 micro-helis were used; damaged helis supplemented our collection of bought spare-parts. Frequent crashes, and at least one instant of a robot being sat on, meant that repair and maintenance was an ongoing process. Extremely light weight components result in a device that is inherently fragile. The micro-helis themselves are not a particularly stable platform, not designed for a regiment of repeated flights involving interactions with scaffolding and actors. Although no mean time between failures is provided by the manufacturer, we believe the hours of flight logged by the operators exceed the time envisioned by the manufacturer.

The severe weight restrictions limited the costume options for the micro-helis. After several experiments, the final costume was a wrap of colored cellophane attached around the innards of the robot once the manufacturer's cowl had been removed. Colored cellophane was also used to wrap the tail. The micro-helis have onboard power LEDS, so the cellophane acted as a filter, making each one uniquely identifiable. The wrap was designed to be removable so that the batteries could be replaced with freshly recharged ones between scenes.

The costumes altered the flight characteristics of the micro-helis, making them somewhat more challenging to fly. The operators also discovered that it was easier to fly costumed helis tail-forward rather than the more traditional tail-backward manner.

The Quad-rotor and micro-helis are very different unmanned aerial vehicles and represent opposite extremes of systems that are feasible for indoor theater use.

4 Production

The production used the New Folger Library Shakespeare 1993 edition (edited by B.A. Mowat and P. Werstine) as the source, from which ±300 lines were excised. The show ran in the Rudder Forum Theatre which has a stage space of approximately 800 ft^2 and holds 250 in stadium seating arranged in a "U" with two levels. The lower seating is divided into three areas by two aisles which were used by the actors along with the main stage. The 6 micro-heli robot operators stood behind the audience in right section, while the Quad-Robot pilot stood in an aisle. *A Midsummer Night's Dream* has nine scenes in five acts; robots participated in five scenes, each of which is discussed in sections below with particular emphasis on how the actors adapted to variations in the flight and crashes of the micro-helis. The presence of the robots did not add any roles or alter the action, with the exception of a prologue which was added to introduce the robots.

4.1 Prologue

A prologue was devised as a way to introduce the robots to the audience separate from the dramatic action. The result was a choreographed dance that featured all the human and robot fairies. The dance showcased each human fairy individually while hinting at their relationship within the play. The robots hovered over the humans and attempted to keep time with the music by rotating back and forth.

The intention here was to get the audience used to the idea and presence of the robots, so that at their next appearance, the audience would keep their primary focus on the dramatic action and not the robots. Our intention worked— the robots were introduced—but the humans never acknowledged the robots during the prologue; doing so would have made the scene even more effective.

4.2 Act 2, Scene 1

This is the first appearance of the fairies into the world of the play. The estranged fairy king (Oberon) and queen (Titania) enter from opposite sides of the stage with their respective entourages. With Oberon is the Quad-Rotor, which flies directly above and behind him during his entrance (see Figure 1), and at his signal, flies away, exiting the scene.

The intention here was to use the Quad-Rotor as a fairy minion of Oberon. Anecdotally, some members of the audience reported neither seeing Oberon's signal nor understanding their relationship; they were perplexed by the Quad-Rotor's sudden exit. Artistically, the Quad-Rotor was prohibitively loud and so had to have a limited presence within the production, if the actor's lines were to be heard without disturbing the pace of the dramatic action. Additionally, the small stage area and dense seating meant that the Quad-Robot had only a few safe corridors to fly without being directly over the audience or an actor and had a small landing zone. Consequently, the Quad-Rotor is not seen again until the last scene of the play, giving credence to the criticism that the relationship between it and Oberon was not as strong as it could have been.

Figure 2. As Titania is cocooned, five human fairies interact with four micro-helis. The two most salient are visible *above* the actors *on the right*. The third is *in the hand* of the green fairy, who is relaunching it. The fourth robot is flying *above the scaffolding*.

4.3 Act 2, Scene 2

Titania enters with her six human fairies and micro-heli fairies; each fairy is costumed with a different color and each micro-heli has a matching color. Titania's fairies sing as they cocoon their queen, all the while the micro-heli fairies hover over the action (see Figure 2). At the end of the lullaby, a fairy waves for the micro-heli fairies to come down. The micro-helis land in the hands of their associated fairy and they all exit.

The intention in this scene was for the micro-helis to complement the enchanted world that Shakespeare created. They hovered above the action and when near a human fairy, that actor would interact with it, establishing what some identified as a mother-baby relationship. The actors learned to interact with the micro-helis in a very convincing manner, improvising petting or cooing to the micro-helis as they landed, or scolding a micro-heli that crashed or was being difficult to catch. By the end of this scene, the relationship between human and baby fairy was crystallized.

4.4 Act 3, Scene 1

Awaking after spells have been cast, Titania seduces Bottom, a laborer who has been turned into a donkey. She calls in her human fairies to wait upon him, and when the human fairies enter, so do the micro-helis. (See Figs. 3 and 4.)

As in Act 2, Scene 2, the intention was to have the micro-heli fairies as a part of the fairy world. The human fairies continue

Figure 3 Four human fairies and five micro-heli fairies are introduced to Bottom by Titania. The two *near stage back and right* are close to mid-air collision.

Figure 4 In the same scene, Mustardseed stoops to pick up and relaunch a crashed micro-heli fairy.

to interact with the micro-helis and, in addition, Bottom notices them. Despite having no direct interaction, Bottom's awareness is an important cue to the audience indicating that fairies can be seen by humans. Unlike the earlier scene, significant dialog is delivered while the micro-helis were in flight. Bottom's lines and braying consistently got laughs, supporting other evidence that the robots did not monopolize the attention of the audience.

4.5 Act 4, Scene 1

Titania, wanting to be with Bottom, dismisses all her fairies (human and robot) and the two sleep. After some time, and intervening foreground action, Bottom awakes and leaves the forest. As he leaves, one of the human fairies and her micro-helis come up behind him to mock and laugh at him.

There were two intentions in 4.1. In the first part of the scene, the intention with the micro-helis is the same as in 2.2 and 3.1 to add to the otherworldliness of the fairies and surroundings. However, in the second part of the scene, during Bottom's exit, the intention was for the micro-heli to contribute to in mocking Bottom. The human actor and the chosen micro-heli had set movements to do together, including laughing and spinning. The human fairy, Mustardseed, would enter the stage carrying her micro-heli as Bottom began exiting and launch the robot from her hand. The robot would follow behind Bottom, who was oblivious to the robot, then it would bounce in the air (*i.e.*, display rapid vertical oscillations) to convey laughter and would spin (*i.e.*, display rapid yaw rotations) at the same time as the human actor spun on the spot.

4.6 Act 5, Scene 1

This is the final scene of the play. Oberon calls for music and dancing, and all the human fairies and micro-helis join them on stage for a dance. As Oberon exits (together with Titania), he gestures up and out, and the Quad-Rotor flies in, waiting for him. Oberon gestures up and out again, and the Quad-Rotor precedes Oberon and Titania out of the theater.

Here the Quad-Rotor could be brought back in a way that made sense dramatically without intruding on the action itself. There were actors still dancing and music was still playing at the entrance of the Quad-Rotor, which made the entrance and the interaction between the Quad-Rotor and Oberon a part of the ongoing action, rather than a special, separate event.

4.7 Curtain call

Once the final monologue has been delivered, the cast return to accept applause and take a bow. At this point the Quad-Rotor and any available micro-helis were flown back on stage. The Quad-Rotor would land center stage (which is the only planned landing maneuver of the play). Micro-helis, launched either by robot operators or by fairies who retained them from the last scene, fly over the stage and interact with the cast. (See Figure 6.) Most catching and relaunching interactions were performed with fairies positioned on the scaffolding, although interactions with other cast members occurred too. After taking a bow, the cast collectively gestured to the robot operators.

Although no attempt was made to obscure the relationship between the micro-helis and operators throughout the play, the curtain call was the only time the robot operators and their role was explicitly acknowledged. Most performances resulted in the audience showing their appreciation by applauding while facing the operators. Because the operators were concentrating on maintaining steady flight, they responded with micro-heli yaw motions. This response at a distance was an unnatural interaction and caused slight discordance.

Figure 5 Mustardseed launches her micro-heli fairy and together they mock Bottom. In ending the scene, the micro-heli flies over the audience. Mustardseed improvises by clamoring over the audience and casting them with a look of scorn for stealing her baby fairy, much to their amusement .

Figure 6 The robots are flown or carried onto stage at the beginning of the curtain call, as the human fairies take their bow.

4.8 Crashes and staging problems

The micro-helis were not always at the right place at the right time, occasionally crashed, and sometimes fewer than six were flown during a scene. The micro-helis were surprisingly fragile, were sensitive to air flow from the ventilation system, and the costumes impacted the control. Operator expertise and availability also varied. In general, the larger number of micro-helis that flew, the more effective their contribution to a particular scene; that is, the number of agents increased comprehension of intent. Fortunately, through the noteworthy adaptability of the human actors, crashes did not distract from play and further engaged the audience.

As shown in Tables 1 and 2, the micro-helis frequently crashed, causing the human actors to improvise. In the Prologue or Final scene (Act 5, Scene 1), the micro-helis did not have an explicit interaction with the actors, and the actors adapted by the closest actor picking up a crashed micro-heli or kicking it out of the way of the dance. (See Figure 7 for a particularly elegant response during this scene.) However in the other scenes, the micro-helis were closely tied to human fairies and their activities, so the human fairies improvised after a crash or would chase a micro-heli that began landing away from the action.

There were two opportunities for improvisation to a crash or errant behavior depending on whether the micro-heli was over the stage or over the audience. If the crash struck an actor or became entangled in a costume or wig, the nearest human fairy might extract the micro-heli and mime scolding it. If the micro-heli simply crashed to the stage, a human fairy would usually pick it up with exaggerated gentleness, and stroke or coo over it as it is were a bruised bird or child, then hold it up to let the operator attempt to relaunch and resume hovering. If the operator did not spin up the rotors or if it were the second crash in a row (the operator presumed a mechanical failure and would not attempt flight again for fear of distracting from the play), the human fairy would just cuddle the robot as she continue her role.

The most interesting variations were when a micro-heli crashed into the audience or drifted over the audience prior to landing. If a micro-heli crashed into the stage first and the audience saw a fairy treating the robot as a baby, the audience invariably duplicated the action. The audience member might be surprised, but not visibly annoyed, and would gently pick up the robot and hold it in their palm to allow a relaunch. The operator would turn off the LED to signal that it wasn't going to fly and the audience member would either spontaneously pass the micro-heli to the end of the row or a human fairy or the stage manager would retrieve the robot at the end of the scene. However, if a micro-heli crashed into the audience first, the audience member was generally disgruntled. Observed reactions by the audience were kicking the robot back onto the stage, throwing

Table 1. Summary of flight statistics collected for the complete run of the play. Noting that even when statistics show low variance, there was typically a turnover of micro-helis

Performance	Prologue	Act 2, Scene 1	Act 2, Scene 2	Act 3, Scene 1	Act 4, Scene 1	Mustardseed flight	Act 5, Scene 1	Curtain call	Operators[a]	Notes
1. Thr 5-Nov	Q_1 + 6/2.3(0.6)	Q_1	6/1.3(1.5)	5/2.7(0.6)	6/3.8(0.8)	1	Q_2 + 6/2.5(1.0)	Q_2 +3/3(0)	BAJKNC	Opening night
2. Fri 6-Nov	Q_1 + 6/1.0(0.0)	Q_1	5/3.3(0.5)	6/4.1(0.4)	6/3.5(1.3)	1	Q_2 + 5/3.0(1.0)	Q_2 +6/6(0)	BTSJKV	
3. Sat 7-Nov	Q_1 + 5/1.2(0.4)	Q_1	5/3.0(0.0)	5/3.0(0.0)	5/1.7(1.2)	1	Q_2 + 4/2.6(0.9)	Q_2 +3/3(0)	TNJKV	
4. Sun 8-Nov	Q_1 + 4/3.0(0.0)	Q_1	4/3.8(0.4)	4/4.0(0.0)	3+1/3.0(0.0)[b]	1	Q_2 + 4/3.6(0.9)	Q_2 +4/4(0)	BJKV	Matinée
5. Thr 12-Nov	Q_1 + 6/3.3(0.8)	Q_1	6/5.0(0.0)	5/3.2(1.0)	6/3.3(0.5)	1	Q_2 + 6/3.3(1.0)	Q_2 +6/4(0)	BATRJC	
6. Fri 13-Nov	Q_1 + 6/4.0(1.0)	Q_1	6/3.4(0.8)	6/4.4(0.9)	6/2.8(1.5)	1	Q_2 + 6/4.1(1.6)	Q_2 +5/5(0)	BANRCS	
7. Sat 14-Nov	Q_1 + 6/2.8(1.3)	Q_1	6/4.3(1.4)	5/3.8(0.8)	6/3.3(0.5)	1	Q_2 + 6/4.7(1.5)	Q_2 +5/3(0)	BAJRCN	
8. Sun 15-Nov	Q_1 + 6/3.2(1.0)	Q_1	6/3.8(1.7)	6/3.4(1.1)	–	–	–	–	BATRJN	Matinée, operators
	–	–	–	–	6/3.5(0.8)	1	Q_2 + 6/4.8(0.4)	Q_2 +5/4(0)	BSKRJV	subst. at intermission

Key: $Q_1 \rightarrow$ Quad-Rotor flight from house left; $Q_2 \rightarrow$ Quad-Rotor flight from house right. $l/\mu(\sigma) \rightarrow l$ = robots launched ; μ = maintained mean of robots in the flight for duration of the scene ; σ = standard deviation of robots in the flight for duration of the scene

a. Mustardseed and Quad-Rotor operators not listed in this column

b. Missed cue, additional robot joined ~20 seconds late

Intermission preceded Act 4.

Figure 7 A dancing fairy carries off a crashed micro-heli by improvising a one-handed cartwheel, robot in hand.

the robot like a baseball apparently intending to relaunch it, or passing it to the end of the aisle. It was significant that the audience did not look to the operators for instruction as to what to do with the robot; the audience member seemed to look for cues on how to behave from the actors or the robot itself.

Particularly during Act 4.1 where Mustardseed and her robot mock Bottom, the micro-heli had a tendency to drift over the audience, although this sometimes happened in Acts 2.2 and 3.1. In order to maintain the fast tempo of the staging, the actor would improvise getting the robot back rather than wait for the operator to try to move the robot back to position. She might reach over the audience or even climb on seats. If the micro-heli had drifted too far, the operator would land in the audience and Mustardseed would gesture for the micro-heli to be returned to her. Mustardseed reacted as if this was all the audience's fault; she mimed scolding the audience and implied that they were trying to steal the micro-heli. In general when a micro-heli drifted over the audience, the audience did not appear to pay attention to it and instead focused on the action on stage. However, there was one exception when a audience member appeared to intend to humorously swat the micro-heli away but the disrupted airflow caused a crash and much embarrassment on the part of the audience member.

5 Audience and actor reactions to interaction

The audience reaction to the use of flying robots was overwhelmingly positive and their unintended interactions with the robots are described in Sect. 4.8, while the reaction of the actors changed from wariness to positive over time. The one review of the play was by the university student paper, The Battalion, which clearly viewed the robots as one aspect of the play

Table 2. Identified unplanned flight events aggregated over the eight performance run of the play

Event	Count
Collision with the scaffolding, side-wall, or curtains	34
Collision with audience	23
Collision with cast	3
Midair collision between robots[a]	10
Downdraft interference	3
Landed on stage or stairs[b]	21
Landed on scaffolding	1
Relaunched from fairy's hand	25
Relaunched from audience member's hand	2

a. A collision between a pair of robots is counted as two collision events

b. This includes robots beyond the line of sight of flyers, and those that land on stage

that accentuated the acting and dancing (Gerhart 2009) rather than the major distinguishing point seen in other uses of robot in theater (Lin et al. 2009; McCoy 2008; Ruggiero 2008). An interesting point is that the reviewer interpreted the micro-heli crashes as due to lost communications, rather than mechanical failure, environmental variability, or operator error.

The robots did not distract the audience from the play as evidenced by the lack of attention paid the robots or operators. No more than four audience members at any performance were observed to follow the Quad-Rotor's exits, despite close proximity to a loud device creating a large air current. As noted in Sect. 4.8, the audience generally ignored the micro-helis when they flew overhead. Consistent with puppetry, starting with Japanese Bunraku which originated in the 17th century and had 3 to 4 puppeteers visibly operating a puppet (Tillis 1992) and continuing through the recent productions of Disney's *The Lion King* and the musical *Avenue Q* where puppeteers are visible, the audience treated robot operators as invisible even though they were in view.

Observations of the actors, statements from the "talkback" sessions after select performances, and a follow up interview with one of the human fairies suggest that the actors had expectations of the robots based on the movies (especially the Terminator) and consumer products (much more hardened and safe). This talk-back is a less formal form of the independently developed Theatre HRI method described in Chatley et al. (2010). The actors had expected humanoid robots and also that the robots might take over roles normally given humans. Initially the actors treated the micro-helis roughly and perhaps being non-science majors did not show an understanding of "naive physics" of flight and continually surprised the robot operators with how the robots were launched. The actors also appeared to be oblivious to the safety hazards associated with the Quad-Rotor. Although it was extremely unlikely that an injury could result, the dancers were often on eye level with the rotors as the robot descended the aisle to the stage. The robot operators gave an official safety and care briefing, creating two analogies that persisted and were mentioned by the actors in their interviews for The Battalion: one was to think of the Quad-Rotor as a "giant flying weed wacker of death" and the other was to think of the micro-helis as robot babies (Gerhart 2009). The metaphors produced the desired effect of a more safety conscious culture. Finally, the actors were at first annoyed at the robots, not the operators, by the limited expressiveness and frequency of crashes. The actors playing the fairies then realized the opportunity for improvisation and to expand their roles. One actor commented that the unpredictability of the robots kept the actors on their toes and not to lapse into inattentiveness. The peer reaction to the "coolness" of having robots in the play also seemed to facilitate the shift from wariness to enthusiasm.

6 Lessons from the theater about affect

The production of *A Midsummer Night's Dream* forwarded an understanding of how affect, an important component of believability in agents, is created. The results are synthesized into a preliminary taxonomy for generating affect. A major surprise was the importance of improvisation and its necessity for even a highly scripted play; the necessity and contribution of improvisation had been eschewed in the literature. The production raises two real concerns that merit additional research: how untrained human groups form expectations about robots (it appears social proof Cialdini (2007) is a major form of influence on those expectations) and the implications of human expectations of safety and reliability of robots (robots may not met those expectations and thus pose significant risk).

6.1 Preliminary taxonomy for generating affect

A goal of the collaborative production was to codify the behaviors would lead to untrained observers perceiving the desired affect and intent. Towards this goal, three categories of how robots can generate affect were identified. The first two categories, *apparent affect from animacy* and *apparent affect from actor reaction*, require that the robot be proximate to the action and only loosely coupled; in essence, the robots do not have to have or execute affective expressions because the overall action or the response of the actors is sufficient to create the perception of affect. Only in the third category, *affect from explicit affective expressions*, does the robot begin to explicitly contribute to the perception of affect. The three categories are ordered by increasing robot affective complexity:

animacy and reaction require less behavioral subtlety from the robot than the explicit affective expression. A weakness of the taxonomy is that it categorizes the effort required by robots to generate affect, rather than organizing the audience's understanding of the affect based on the contribution of mechanisms (proximity, synchronization, mirroring, sounds, etc.). Even without a detailed model of the audience's understanding of affect, important distinctions of degree or kind of affect may alter which taxonomic categories are applicable. Apparent affect by actor reaction was the dominant mechanism in the play; in all but one case, the actors led the action and their reaction created the affect. While robot capabilities or operator skill may limit expressions of affect to the first category or first and second categories, the experience is that this need not imply a hard limit on the expressiveness of the robot. Within the first two categories a lack of complexity in the individual robot is compensated for by other agents: the observed robot-actor relationship and interaction is the expressive element, rather than the robot itself. When generating affect the robot should be considered a socially situated agent within a broader ecology of agents, the scene, and staging.

6.1.1 Apparent affect from animacy (the Heider-Simmel effect)

Consistent with the seminal Heider and Simmel study that showed observers assign affect and interpret intent based on motion (Heider and Simmel 1944), the audience perceived affect and group coordination even though the robot motions where independent of the actors' motions. As seen in the Prologue and Acts 2.1 and 5.1, the connection between the actors and robots was through accidental *proximity* and *loosely coupled synchronization*. For example, in the Prologue, the goal for each robot operator was simply to get their robot over the dancers and, if the mechanical control and environmental conditions permitted, to rotate their robot to the beat of the music. The apparent affect was perceived more strongly when there were more robots, possibly because the probability of a favorable synchronization confirming an intent was increased (e.g., "that robot is moving to the beat; oh, all the robots are excited by the music …" or "those two robots are above the action, they all must be watching the action"). Demers and Horakova (2008) refer to animacy in performing robots as anthropopathy, a term from theater denoting the attribution of affect to non-human beings.

6.1.2 Apparent affect from actor reaction

Consistent with stage theory, where the visible reaction of the actor to an action by another actor creates the impression of affect, the human actors can create affect even if the robot's actions are independent. This type of apparent affect occurred in Acts 2.2, 3.1, and the first part of 4.1, where the micro-helis swarmed overhead and then landed in the human fairies' hand, creating an impression of baby fairies. Unlike the Prologue and Acts 2.1 and 5.1, there was explicit interaction between the actors and robots but the human was expected to compensate for deficiencies in the robot. For example, the lead fairy cued the robots to descend and then all fairies attempted to gracefully catch the robots. The actors compensated for the robots' lack of control and unpredictable locations, creating an impression of cooperation. Rather than the robots or their operators keeping up with "their" mother fairy, the mother fairies were expected to keep up and compensate for the robots.

The robot's contribution to the generation of affect in this case was *proximity* and a more *tightly coupled interaction* (i.e., descend on cue) but the responsibility for the perception of affect relied on the skill of the actors, very precise stage directions, and an awareness on their part of the situation, and their ability to improvise.

It is interesting to note that the audience learned how to interpret the robot agent's actions based on the actor's reactions; as described in Sect. 4.8, the response of an audience member to a robot crash depended on whether they had witnessed an actor responding to a crash.

6.1.3 Affect from explicit affective expressions

In this category, the robot initiates and performs some, if not all, of the direct cues to create affect, with a much lessened dependency on the reaction of the actors. In some sense, this is where a robot can deliberately project affect and intent. Only one scene in the play had a robot attempt to create affect using explicit affective expressions. In that act where Mustardseed mocks Bottom, a robot baby fairy is launched by a mischievous Mustardseed, it then moves away from Mustardseed to follow behind Bottom while making a set of mocking (up/down, roll/yaw) motions and "sneaky" noises like Snidely the Dog (the sound was not added for technical reasons), then spins to communicate enjoyment of the prank. Note that in theory, the interpretation of affect in this category would depend more on what the robot actually does independently of the actors. However, this was only weakly demonstrated in *A Midsummer Night's Dream*; the success of the act depended on the actor who non-verbally conveyed mischievousness before and during launching her robot baby and that impression was transferred and attached to the robot. It should be emphasized that the actor was chosen for her ability to set up the affective nature of the scene, and other actors in the production would not have been as successful as she.

6.2 The importance of improvisation within robot theater

Perhaps the most surprising aspect uncovered while creating the taxonomy was the degree of improvisation required of the human actors and the lack of improvisation required by the robot. While improvisation is a key element in digital character animation (see Perlin 2000 and Göbel et al. 2006 for representative approaches), the prior work in the nascent robotics theater community has argued that actor-robot improvisation would be too hard (Breazeal et al. 2003) or that anything but improvisation would be unsatisfying (Bruce et al. 2000). This work found that improvisation by the actor was both necessary to stage a production with robots and effective in communicating and amplifying affect within a scripted play, but that the robot did not have improvise. It also found that symmetry is not required; robots do not have match human capabilities in improv.

The use of improvisation runs counter to Breazeal et al. (2003), which postulated that improvising would be the hardest case of interaction for robot and human actors and thus should be attempted last. However, Breazeal et al. (2003) only considered fully autonomous robots, while this effort shows that the robot does not have to be the improvising party. The experiences with *A Midsummer Night's Dream* show that improvisation is required both implicitly (to compensate for timing, actor variations, etc., also seen in Apostolos et al. 1996; Wallis et al. 2010) and explicitly (to compensate for technological failures, such as the crashes in Sect. 4.8). The implicit and explicit opportunities for improvisation may be thought of as de facto "scene-advancing offers" Baumer and Magerko (2009), the initial step in effective improvisation. Furthermore, the taxonomy shows that it can be simpler from a programming standpoint to produce believable characters with improvisation than without (which is consistent with digital character animation), as creating apparent affect from animacy and actor reaction is less complex for a robot than explicit generation of affect. Therefore, improvisation should be expected to be incorporated into any human-robot theater production both from necessity and from simplicity. If Breazeal et al. (2003) argue for improv being attempted last because it is so difficult, then the findings from *A Midsummer Night's Dream* suggest improv is easy and should be attempted first.

The clear audience acceptance of robots as an enhancement to *A Midsummer Night's Dream* and their demonstrated enjoyment of the play described in Sect. 5 contradict Bruce et al. (2000) who argue for robots in fully improvisation drama saying that "Having robots perform a prescripted, complex play (say, Hamlet) would be an obviously unsatisfying experience." Bruce et al. (2000) can be interpreted in a less extreme "do away with scripts" fashion as a fear of the loss of dynamic coordination and timing between actors. However, the lessons learned from *A Midsummer Night's Dream* was that while such timing is critical for an enjoyable play, the robot does not necessarily have to be responsible for it. Affect can be generated with unsynchronized timing (apparent affect from animacy) and from the human actor (apparent affect from actor reaction). Certainly having autonomous robots which can observe and respond appropriately is a goal, but in terms of the goal of this article, *A Midsummer Night's Dream* shows that the robot may not have to explicitly generate or be responsible for affect production.

6.3 How untrained human groups form expectations

The observations of the actors during pre-production and the audience suggests that people base how they will interact with robots from watching others. This appears to be an extension of the concept of "social proof" forwarded by Cialdini (2007). Social proof is the phenomena of responding to a situation based on the observations of how others are responding. One example is that despite reporting hating canned laugh tracks, people will laugh longer and more often with it. Cialdini notes that social proof is especially pronounced in ambiguous situations; if a person does not know what to do, they look to see what others are doing. An example includes bystander inaction, such as the famous Kitty Genovese case where 38 people witnessed her murder but did not intervene. However, social proof applies to any uncertain situation where there are large numbers of people who are not acquainted. The witnessed behavior of the actors, and especially that of the audience, suggests that social proof will be the default mechanism at play in first encounters between the public and a robot(s). The default social proof of human-robot interaction from the movies must be managed or replaced so that the correct expectations are formed or reinforced and people respond appropriately.

Social proof appears to have influenced the actors' response to the robots, but more importantly the actor's source of social proof helps explain the audience's stronger exhibition of social proof. During pre-production, the actors had very little interaction with the robots and as a group were not told how to react to the robots; only the individual human fairies were formally introduced to the robots and that was brief as the frequency of crashes and potential for unsafe interactions was not anticipated. This created an ambiguous situation with a large number of people present, though many of the cast members knew each other. As reported in the talk-back sessions in Sect. 5, the actors stated that they started off with expectations formed by movies and TV and previous interactions with hardened consumer goods. This suggests that social proof of how to behave around and with the robots was provided by the media; Cialdini reports that therapists often use films of threatening experiences and how others behave in that context to provide social proof of how to respond appropriately (Cialdini 2007). Possibly as a result of the prior social proof in the media of robots as capable, advanced agents, the actors were surprisingly trusting of the large robot, coming far too close to the exposed rotors, and being too rough with the smaller platforms. The actors' default expectations had to be modified by explicit instruction so that they would maintain a safe distance from the larger AirRobot platform and would handle the fragile Eflite platforms more carefully.

Social proof appears to be the best explanation for the variances in audience reaction to a small robot fairy crashing in the seated area. As described in Sect. 4.8, if a crash into the audience occurred *after* a crash on-stage where a cast member relaunched a robot, the nearby audience members would treat the robot in the same gentle way and use the same careful motions to relaunch. If a crash occurred *before* an on-stage crash and relaunch, the audience members often looked around then were generally rough and threw the robot to relaunch. A crash into the audience met all three conditions for social proof: the occurrence of the crash (and the presence of the robots at all) created uncertainty as how to respond, there was a large number of people present, and the audience and cast were not acquainted. Consistent with social proof, the audience reaction to a crash was based on what they observed up to that point. If they had observed actors handling the robots, they followed that model, if they had not, they were likely using the same expectations as the actors formed by the media and consumer goods. Unlike the talk-back sessions with the actors, there was no questioning of the audience to explore their state of mind, so this remains a conjecture.

6.4 The importance of safety and reliability

Although safety and reliability might be considered an expectation of an untrained human group, the impact on robot physical design and human-robot interaction behaviors warrants a separate discussion. Both the actors and audience appeared to treat both the large Quad-Rotor and the small micro-helis as safe. Only when explicitly informed of the potential for injury did the actors maintain an appropriate distance from the Quad-Rotor. Likewise, both the actors and audience treated the micro-helis roughly and launched them from demanding positions without apparently considering the consequences.

Safety and reliability is particularly important in theater as proximity may be the most important factor in generating affect. Affect requires proximity between robots and humans, but close proximity introduces risk to the humans (and robots, as seen by the audience member swatting a robot).

Safety and reliability is also a design issue; how will robot designers meet the expectations of safety and reliability or indicate that the default expectations are incorrect? One way to indicate that a robot is unsafe or to encourage maintaining a safe distance is to behave erratically; however, the AirRobot Quad-Rotor is designed to be stable and is hard to produce noticeable erratic behavior without risking the platform. The micro-helis had one way of communicating state: the LED that illuminated the costume. An operator would turn off the link to a micro-heli, causing the LED to turn off, signaling that the robot was inoperable. Significant attention was paid to safety during pre-production and scenes and stagings were cut or modified to minimize any possible risk to the audience.

7 Conclusions

In conclusion, the successful production of *A Midsummer Night's Dream* with humans and robots provides insight into creating believable agents. Seven non-anthropomorphic aerial vehicles with only a few degrees of freedom to provide expressiveness were able to amplify the emotional content of the play.

The experience produced a preliminary taxonomy of how robots can generate affect. Affect can be generated with no explicit behaviors as a consequence of the assignment of causality to animate objects (apparent affect from animacy). It can also be generated without explicit affective behaviors through the response or context setting by the actors (apparent affect from actor reaction). As the third level of complexity, the robot itself can explicitly contribute to the perception of affect (affect from explicit affective expressions). Lessons learned for creating apparent affect include having robots in close proximity to humans, multiple robots do not have be tightly coordinated or synchronized to generate affect, and having more robots increases the understanding of intent when robots are performing in parallel to humans (i.e., humans aren't providing direct cues). There remains the question of whether affect production in the theater, which is surreal, will hold for real world public encounters with robots.

The production also illustrates the importance of improvisation to be a workable and desirable means for interacting with robots. Such improvisation is necessary to overcome the natural behavioral variability in theater and also the results of control error, noise, and uncertainty. While *A Midsummer Night's Dream* relied on the human actors to be the improvisational agent, it is expected that improvisation will be a fundamental component of believable agency and not an optional, advanced case.

The research also identified that much more work needs to be done in how people generate expectations about robots and the implications for safe and reliable interactions.

Future work is expected to continue to refine the ideas put forth in this article, especially addressing how the audience perceives for affect (versus how a robot can generate affect). Plans for another human-robot production are underway and a new play with key roles for robots has been proposed.

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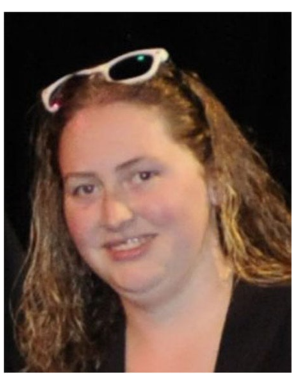

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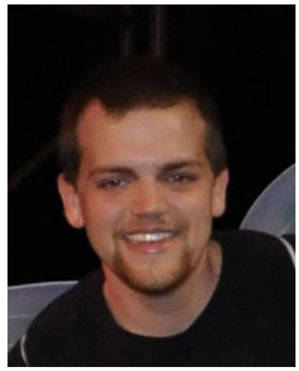

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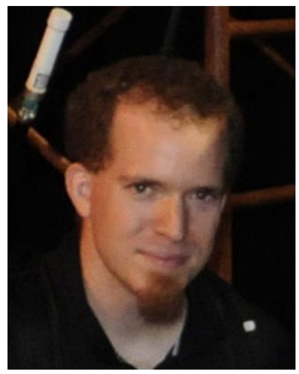

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