Do You See the Magic?
An Autonomous Robot Magician Can Read Your Mind

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ABSTRACT

For most people magicians seem to surpass human abilities, combining skills and deception to perform mesmerizing tricks. Robots performing magic tricks could similarly fascinate and engage the audience, potentially establishing a novel rapport with human partners. However, magician robots are usually done by Wizard of Oz. This study presents an autonomous framework to perform a magic trick in a quick and game-like human-robot interaction. The iCub humanoid robot plays the role of a magician in a card game, autonomously inferring which card the human partner is lying about. We exploited cognitive load assessment via pupil reading to infer the mental state of the player. The validation results show an accuracy of 90.9% and the possibility to simplify the game to improve its portability. This suggests the feasibility of our approach and paves the way toward a real-world application of the game.

KEYWORDS

Magic; autonomous; humanoid robot; human-robot interaction; pupillometry; cognitive load

1 Introduction

Magic is mesmerizing, it has fascinated humans since the very beginning of humankind. We created myths, traditions and legends on it. Nowadays, even with technological developments, magic is still present, often in the form of a combination of technology and deceptive abilities. Recently, robotics researchers started exploring magic mainly in the entertainment field. One example is the IEEE Human Application Challenge (HAC): Robot Magic and Music [1], [2] where technology, crafting and deception are mixed together creating amazing performances. However, providing funny and interactive activities is a feature underexplored in robotic research. Beyond these research purposes, it could help spreading robots in the society, as novel tools for entertainment. In the last years, several robotic platforms [3]–[10] and frameworks [11], [12] for these applications have been developed. At the same time, researchers started exploiting games and entertaining tasks as scenarios to investigate human-robot interaction. In literature it is possible to find several examples, such as rock-paper-scissor [13], [14]; mime [15], [16]; storytelling [17]–[19]; UNO [20]; treasure hunt [21]; and others [22], [23]. Few of them are also exploited for education [4], [7], [24], [25] or therapy [10], [26]. Few attempts have been done so far in the specific field of magic and magic tricks. Most of them are related to the IEEE challenge [1], [2], [27], [28], or focus on base-level magical concepts like distracting player's attention [29], handling cards [30], or defining the correct interaction timing [28], [31]. However, they mostly depend on a Wizard of Oz control configuration, with the "wizard" either hidden or present on stage, and using the robot as a puppet.

Inspired by the television show *Box of Lies* [32], we present an autonomous framework to play an entertaining magic trick with the iCub robotic platform [33]. iCub guesses in real-time the player's *secret* card (randomly extracted from a six-cards deck) during a brief, social interaction. The game is based on our previous findings [34], [35] on lie detection in HRI based on cognitive load assessment [36], [37] via pupillometric features [38], [39]. In the current paper, we describe the magic trick, the architecture on which it is based and the validation experiment. Our framework was able to guess the player's *secret* card with an accuracy of 90.9% (respect to a chance level of 16.6%). Finally, we discuss future improvements and possible applications.

2 Game Framework

During the magic trick, the player sits in front of iCub, with a table (covered with a black cloth) between them. On the table lie six equidistant green marks; a deck of six cardboard cards with blue back, and a Tobii Pro Glasses 2 eyetracker (see Figure 1). As the game starts, iCub asks the player to take the deck, shuffle it, draw out a card (iCub calls it *secret* card), memorize it and put it back in the deck. Then iCub asks to look at all the cards one by one, shuffle the deck again and place the cards on the table, covering the six green marks. iCub says that, in order to perform a magic trick, it is going to point each card one by one and it instructs the player to take the pointed card, describe it and put it back on the table. It says: "*The trick is this: if the card you take is your secret card, you should describe it in a deceitful and creative way. Otherwise, describe just what you see*". Then it asks to wear the Tobii Pro Glasses 2 and it starts to point at the cards. Finally, iCub guesses the player's card and asks for a confirmation.

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Figure 1: Game room setup with a deck of six cards with blue back, six green marks on the table and the Tobii Pro Glasses 2 eyetracker.

In particular, iCub guesses the *secret* card exploiting the heuristic method presented in [34]. The method is based on the fact that the fabrication of a creative and deceitful description for the *secret* card triggers a cognitive load peak in the player. This cognitive load reflects on a higher mean pupil dilation with respect to the other cards. In order to make iCub capable of autonomously handle the game and guess the player's card, we implemented the framework seen in Figure 2. All the components, except for the Tobii Pro Glasses 2 and its proprietary software, interact via YARP [40] robotic platform – which also guarantees the synchronization of stored events and features.

2.1 Tobii Streamer

By default, the Tobii Pro Glasses 2 eyetracker records pupillometric features at a frequency of 100 Hz and generates reports for post-hoc analysis. In order to stream pupil dilations in real-time on YARP we implemented the *Tobii Streamer* (extending the python module Tobii Glasses Py Controller [41]). The module collects player's pupil dilations from Tobii Pro Glasses 2 eyetracker and streams them on YARP robotic platform. During the game, both Tobii proprietary software and our *Tobii Streamer* work together. This setup allows us (i) to collect the pupil dilations in real-time, in order to perform the magic trick; and (ii) to record and store all the pupillometric features in standard format for future analysis.

2.2 *Secret* Card Classifier

The *Secret Card Classifier* makes iCub able to detect the player's *secret* card exploiting the heuristic method. It collects the streamed right-eye pupil dilation features during the descriptions, computes the mean scores and predicts the *secret* card. Mean pupil dilation features are aggregated from the moment when players take a card to the moment when they put it back on the table (we refer to those intervals as *player* intervals). Before evaluating the *secret* card, the features are normalized with respect to the average pupil dilation during the five seconds before the first pointing [34], [42]. We have chosen to focus on right-eye features since prior findings on lie detection based on pupillometric features [35] and Tobii's documentation [43] reported no significant difference between the two eyes.

2.3 HSV Blob Detector

From our previous experiment [34] we collected a great variety of description durations (from 1.8 seconds to 1 minute and 17 seconds). Hence, it is important to adapt the interaction to each player, choosing the right timing to perform multiple pointing. We decided to implement a visual-based approach in which the system knows when the player takes a card by detecting at least a green mark on the table; it knows when the player puts back the card on the table by detecting at least 6 blue squares (cards) and no green marks. The *HSV Blob Detector* counts the number of blobs in a region of interest on the table in order to minimize the false positives.

2.4 Game Controller

The *Game Controller* manages iCub's speech and movements. The robot explains the initial rules and generates a random sequence of pointings. These actions are performed in a human-like manner by initially moving the gaze and then the arm and body. In order to increase the engagement of the player and provide a better social interaction, iCub acknowledges the end of each description with a simple feedback sentence (e.g. *"ok", "mh mh", "I see")*. The controller also stores the timestamps related to the beginning and the end of each time interval in which the human action is performed for further analysis.

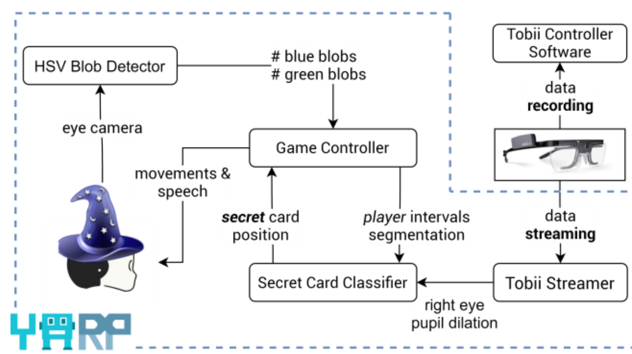

Figure 2: Game framework and data workflow

3 Framework Validation

We asked 12 participants – all Italians, 6 males and 6 females, average age of 26 years old (SD=1.6) – to take part in a validation experiment. The experimental room was arranged as showed in Figure 1. The room was lit with artificial light and the window blinders were closed to ensure the same light conditions for all the participants. The experimenter asked the participants to sit on the chair in front of iCub and left the room. iCub led the whole game as described before: it made the participants draw out their card, presented the game rules, pointed the six cards one by one and finally guessed the participants' *secret* card. The experimenter monitored the interaction through iCub's visual and audio sensors in order to intervene in case of malfunctions.

4 Results and Discussion

The main objective addressed in this work is to make iCub able to autonomously perform a quick and entertaining magic trick with a human player. We discarded one of the participants because Tobii eyetracker malfunctioned leading to an insufficient number of collected datapoints. Considering the remaining 11 participants, iCub correctly guessed 10 out of 11 *secret* cards reaching an accuracy of 90.9% (against a chance level of 16.6%). The only participant, whose card was not guessed, self-reported a premeditated behavior: the player started to think about the creative and deceptive description when iCub presented the rules. We previously observed a similar premeditated behavior [34] but limited to just before the begin of *secret* card's description. We speculate an even prior premeditation could reflect on a higher cognitive load for the other cards, which description was not prepared in advance.

In order to provide more support to our findings, we post-hoc analyzed the segmented data. We computed the average of each feature for the *non-secret* cards and compared it with the same feature for the *secret* card. Both Shapiro-Wilk [44] and D'Agostino k-squared [45] tests showed that data were not normally distributed. Wilcoxon signed rank test [46] between *secret* ad *non-secret* cards showed a significant difference during *player* interactions. Also, the features during the whole interactions resulted to be significantly different. This statistical result is present even without normalization with respect to the baseline (average dilation during the 5 seconds before the first pointing). These findings suggest the possibility to apply an even easier process without the baseline normalization and with a coarser interval segmentation. We validated this hypothesis computing the heuristic method based on the mean pupil dilation during each card's whole interaction: from the begin of the pointing to the moment in which the player puts the card on the table. This heuristic reached an accuracy of 81.2% (against a chance level of 16.6%). We speculate the accuracy could increase using a combination of multiple features. The proposed heuristics are still limited to tasks in which the presence and uniqueness of a deceitful description is on a finite set of items is a priori known. However, they are general enough to perform the magic trick.

We focused on two main objectives during the game design: (i) providing a human-robot interaction (HRI) as ecological as possible; and (ii) designing an interaction feasible to be played as a demonstration of our research activities. The requirements limited the method used to detect the beginning and end of each card's description. Assuming a demonstration is played in a crowded space, a speech or voice activity detector was not feasible. We also excluded the usage of QR-codes or other machine-readable markers in order to avoid the player's assumption that iCub could understand the cards by reading the mark. We are aware that, even if our HSV blob detector can quickly understand the scene, it has several limitations (*i.e.* environmental light conditions, camera calibration or false positive due to same colors in the scene). However, its lack of robustness is compensated by the double-check of cards and marks presence – one of the participants wore a blue shirt that did not interfere with the gameplay, even if detected as a card. For the future, we plan to improve the reliability of the card detector with our ongoing research on feature-based object recognition and localization. This way it will also be possible to remove the green marks on the table, improving the portability of the game. During the game, we decided to do not calibrate the Tobii eyetracker in order to improve player's immersion in the game avoiding a cumbersome process that could break the social interaction and magical atmosphere. Even if calibration is mandatory to measure user's gaze direction, it does not affect the Tobii Pro Glasses 2's ability to measure pupil dilation, as reported by producer's specifications. In any case, the usage of a head-mounted eyetracker system is another limitation to the ecology of the interaction. However, recent developments [47] on RGB cameras suggest the possibility to detect pupillometric features with traditional devices, portable on robotic platforms. This could also improve the turn-taking by implementing a mutual gaze detection to understand the end of cards' description (solution not feasible now due to the eyetracker occlusion). The simplicity of the proposed framework makes it feasible to be executed on robot boards, minimizing the necessity of external devices. The division of roles between components makes the framework easily expandable and customizable based on the specific scenario. We implemented the framework on iCub robotic platform; however, the *Game Controller* could be adapted to any robotic platform able to present the cards in a proper way. Since the *secret* card classification system is based on cognitive load assessment, the identity of the stimulus is not strictly important for the task. The playing cards could be replaced with other objects depending on the specific contexts and objective of the task. In this frame, the game could be used to assess cognitive load in a quick way and act consistently (*i.e.* in educational or rehabilitation scenario) or adapt robot's behavior to the partner during multiple interactions.

Our future work will focus on generalizing the presented approach. We are going to replace the current playing cards with a bigger, more professional, deck from which randomly extract the set of items for the magic trick. We also plan to perform multiple sessions in order to better explore the presence of deceptive strategies and the possibility to adapt iCub's behavior. Finally, we will enlarge our previously collected dataset [34] with the data collected during this validation experiment and future sessions. Our purpose is to train a machine learning model that overcomes the limitation of the heuristic, providing robustness and generalization.

5 Conclusion

This work demonstrates the possibility to develop a light autonomous framework to perform a magic card trick with iCub robotic platform. This task could be used to present a fun and entertaining human-robot interaction perfect to show research developments to a broad range of people. It could also be adapted to assess the cognitive load of a human partner in a non-intrusive way. This ability is relevant in fields related to tutoring, caregiving or security. For instance, a companion robot could detect if a child did the homework or a patient took the medication and act consistently. Our hope is that the development of entertaining tasks could minimize the gap between humans and robots making them more acceptable in the society.

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