What If Robots Could Tango?

I. Background/motivation

The coexistence of robots and humans is the vision of the not so distant future of Cyber-Physical Systems (CPS), in which machines and humans are required to perform tasks cooperatively, and transcend the limitations of either unaided humans or automation acting alone. In the CPS of tomorrow machines and computers will be our co-workers. They will speak and understand natural language, engage all our senses (touch, smell, etc.), understand what we want from the context, and adapt to our emotions. Embedded in our living environment or hidden as everyday objects in our clothes or behind 3D interfaces, we will simply forget about them and enjoy the magic they create. In this perspective, it is our today's goal to design robots which are able to communicate continuously and bidirectionally with humans, feel their emotions, and perceive the surrounding environment. The robots of the new generation, equipped with a Cyber-Behavioral Adaptation (CBA) unit, must be able to take decisions (improvise and lead) based upon information received and perceived from the overall system, or comply with other's decisions (follow).

Autonomous improvisation has remained a neglected topic in robotic studies for far too long. No interdisciplinary approach to multi-agent robust CPS with real-time CBA currently exists, which can be used as a schema to conduct research at the intersection of human factors, psychology, computer science, and robotic systems. This research will close a key gap by developing intelligent cyber-robotic systems that can deal with concurrent human skills and emotions, and addressing the explicit implementation of emotional behavior interfaces to ensure that robots adapt to humans' current internal states. Of special interest is the design of control laws for the cooperative robots that will capture human behaviors while accomplishing multiple objectives. We believe that this is a necessary step we must undertake, since it will enhance robustness and safety of CPS, and it will contribute to the development of the technologically friendly society of the future.

The integrated framework resulting from this project will be applicable to a broad class of multi-agent CPS, including the ones that have close presence of cooperative robots to humans, autonomous inspection of space systems, and search/rescue missions, to name a few.

II. Proposed research/work

A robot who is able to lead and follow its teammates/partners (humans and/or robots), feel their emotions, improvise, and safely cooperate in a human environment, is a robot who can definitely *tango*. Argentine tango is an improvisational pair dance (leader/follower) often distinguished for its complexity, expressive quality, creative potential and, of course, for its elegance. Tango goes well beyond more limited kinds of interaction, as the actions of tango dancers interlace with each other and with the music continuously. In technical terms, cooperation and coordination between the tango partners is co-regulated (i.e. *"the continuous unfolding of individual action is susceptible to being continuously modified by the continuously changing actions of the partner" - Alan Fogel*):

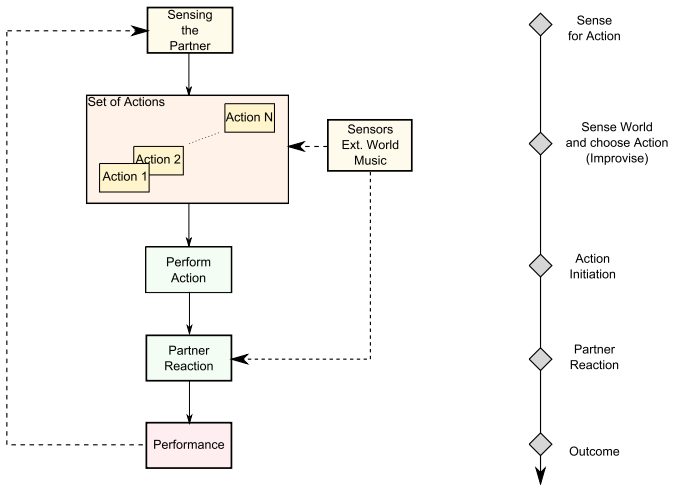

Fig. 1: Tango as an intuitive model for CPS.Model of leader behavior, follower behavior and success in tango and CPS

feedback is received while online decision making (improvised actions) continuously modifies the structure and configuration of the dance.

For these reasons, the final goal of this research is to design control algorithms that enable (aerial) robots to dance tango, with the understanding that this is only an artistic illustrative application, and that the outcome of the proposed work is intended to be incorporated in the general domain of cooperative human-robot CPS.

The robot-dancers will be capable of: (i) sensing their partners/teammates awareness and comfort level with respect to their decisions so that they can, if needed, adjust their actions; (ii) sensing whether their partners receive enough feedback and whether their own actions correspond to the invitations they receive; (iii) interpreting the music (which can be seen as a low level command sent from a supervisor to the overall CPS), navigating the dance floor to avoid collisions, feeling and directing the partner, and taking actions in relation to all these parameters. Figure 1 depicts the proposed framework.

III. Potential impact in/to CPS

The interdisciplinary nature of this research will embrace CPS in their full complexity, spanning control theory, optimization, psychology and human factors. This research ensures (i) that benefits of robotic technologies can be drastically improved when machines are able to adapt their behaviors to the changes of human emotional states, and (ii) that such benefits can be realized under realistic assumptions about automation capability and reliability. The resulting cyber-behavioral adaptive cooperative robots can be effectively used in search and rescue missions, healthcare industry, intensive care units, robotic housekeeping, to mention a few. It is well noted that in social cooperative interactions, implicit emotional communication plays a crucial role. A robotic system that is capable of such affective communication with humans (operators, patients, etc.) and that can modify its behavior if required, will bring CPS to the next level.