in: IEEE Int. Symp. on Robot and Human Interactive Communication (RO-MAN), Lisbon, Portugal, pp. 1351-56, IEEE 2017

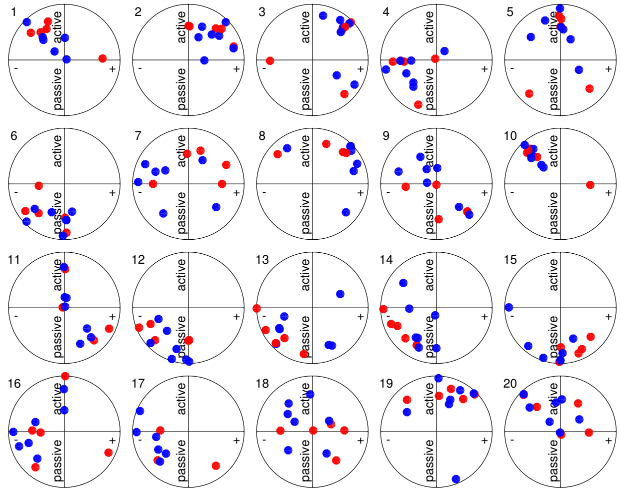

Fig. 4. Emotion labels of the autonomous navigation experiment (blue - male, red - female). The robot performed emotional movement patterns while targeting a goal in the hallway of our institute building while 11 participants observed and rated their impression in the 2D-ES.

the velocity commands are directly relayed to the motor controllers resulting in a relatively direct replication of the model robot's movements.

During the experiment, in each case, one of the participants controlled the robot along a hallway of our institute building, while the remaining audience observed it and had to note their impression by means of a cross in the 2D emotion circle on a form. During the runs, the actual movement trajectory of the robot was recorded. The group consisted of staff members and students of our lab in age between 24 and 50 with 5 female and 7 male participants.

The visual analysis of the label data showed, that there are patterns that make a similar impression on the observers, but others are ambivalent (also visible in the data of the second experiment shown in Fig. 4). Since the "puppeteer" had a certain emotion in mind for each trial, for most of the parts of the 2D-ES a significant pattern could be generated at the end. Only the lower right quadrant representing the relaxed mood is not covered sufficiently.

After the velocity patterns were recorded, the robot was able to perform the movement patterns autonomously. Therefore, the recorded velocity profiles have been trimmed manually to only contain the desired pattern going in a straight direction, and the emotional objective function was used as described above but only one template T_j was active at a time. Finally, 19 patterns have been generated using the earlier recorded velocity profiles.

In a second experiment, the participants had to label the perceived emotion again while the robot drove autonomously, resulting in the data shown in Fig. 4. During trial 20, the emotional objective function was disabled as a reference, which results in the "normal" navigation behavior. The label data shows that the impression is slightly biased towards the active side of the 2D-ES in that particular case, which is due to the faster and goal-directed motion compared to the patterns with the activated emotion objective.

An analysis of the emotion labels showed, that the autonomously generated movement patterns are of a similar quality as the manually driven patterns with respect to perceivable emotions. A comparison of the average standard deviation of the emotion labels given by the observers for manually driven trajectories (0.471) and the autonomously driven (0.493) shows that there is no significant difference in the interpretability of the patterns. The concentration of labels in different sectors of the 2D-ES shows that there is a common sense of emotional interpretation of movements in the group as supposed in the beginning.

VI. CONCLUSIONS

We could show that it is possible to realize an autonomous motion controller for a mobile robot, that is able to combine safe, goal directed navigation with emotionally expressive movement patterns. In order to overcome arbitrariness in the design of emotional expressive patterns, we suggested to involve opinions of a group of people voting the performed movement patterns directly in a real-valued emotion space and demonstrated the feasibility of such an approach. Open issues to be considered in future developments are alternative models for the emotional objective function also taking into account further context information (e.g. spatial distances to users and obstacles). Nevertheless, the approach of using only the velocity profiles without any context information showed a good performance in our user experiments.

REFERENCES

[1] C. Schröter, S. Müller, M. Volkhardt, E. Einhorn, C. Huijnen, H. van den Heuvel, A. van Berlo, A. Bley, and H.-M. Gross, "Realization and user evaluation of a companion robot for people with mild cognitive impairments," in *IEEE Int. Conf. on Robotics and Automation (ICRA)*. IEEE, 2013, pp. 1145–1151.

[2] H.-M. Gross, S. Müller, C. Schröter, M. Volkhardt, A. Scheidig, K. Debes, K. Richter, and N. Döring, "Robot companion for domestic health assistance: Implementation, test and case study under everyday conditions in private apartments," in *IEEE/RSJ Int. Conf. on Intelligent Robots and Systems (IROS)*. IEEE, 2015, pp. 5992–5999.

[3] Sympartner project page. [Online]. Available: http://www.sympartner.de

[4] F. Heider and M. Simmel, "An experimental study of apparent behavior," *The American Journal of Psychology*, vol. 57, no. 2, pp. 243–259, 1944.

[5] T. H. H. Dang, G. Hutzler, and P. Hoppenot, "Mobile robot emotion expression with motion based on mace-grace model," in *2011 15th International Conference on Advanced Robotics (ICAR)*, June 2011, pp. 137–142.

[6] P. Gebhard, "Alma: A layered model of affect," in *Proceedings of the Fourth International Joint Conference on Autonomous Agents and Multiagent Systems*. ACM, 2005, pp. 29–36.

[7] J. A. Russell, "A circumplex model of affect," *Journal of Personality and Social Psychology*, vol. 39, pp. 1161–1178, Dec. 1980.

[8] D. Fox, W. Burgard, and S. Thrun, "The dynamic window approach to collision avoidance," *IEEE Robotics Automation Magazine*, vol. 4, no. 1, pp. 23–33, Mar 1997.

[9] S. Müller, T. Q. Trinh, and H.-M. Gross, "Local real-time motion planning using evolutionary optimization," in *Proceedings of Towards Autonomous Robotic Systems (TAROS)*, 2017.

[10] R. Philippsen and R. Siegwart, "An interpolated dynamic navigation function," in *Robotics and Automation, 2005. ICRA 2005. Proceedings of the 2005 IEEE International Conference on*. IEEE, 2005, pp. 3782–3789.

[11] C. Leibig and S. Wahl, "Discriminative bayesian neural networks know what they do not know," in *NIPS Workshop: Deep Learning and Representation Learning*, 2016.