様　式　Ｃ－１９、Ｆ－１９、Ｚ－１９　(共通)

科学研究費助成事業　　研究成果報告書

平成 ２８ 年　 ４ 月 ２５ 日現在

機関番号：１４４０１
研究種目：研究活動スタート支援
研究期間：2014～2015
課題番号：２６８８００１４

研究課題名（和文）Development of a humanoid robot motion teaching system based on the interpretation o f tactile instructions

研究課題名（英文）Development of a humanoid robot motion teaching system based on the interpretation of tactile instructions

研究代表者
ダーラリベラ　ファビオ（Dalla Libera, Fabio）

大阪大学・基礎工学研究科・特任助教(常勤)

研究者番号：８０７４００９２

交付決定額（研究期間全体）：（直接経費）　　2,100,000円

研究成果の概要（和文）：ロボットは，日常生活の根幹として活躍することが期待されている．中でも人間型ロボットは，人間に類似した形態を持ち，人間の使う道具やインフラをそのまま使うことができるほか，人間にとってロボットの状態や特徴，限界が推測しやすいという利点がある．そのため，ロボットに関する知識のない人も，ロボットに新たな動作を教えることが容易になると考えれる．
人が人に動作を教える場合に注目すると，スポーツコーチやダンスの先生は直接触れて教えることで，生徒に直感的に多くの情報を伝える．本研究は，このようは教え方を人間型ロボットにも可能にするため，接触による教示に対して意図通りのロボットの反応を生成する手法を提案した．

研究成果の概要（英文）：In the near future, robots are expected to become an integrant part of the society. Among robots, humanoids present, thanks to their human-like shape, are expected to assume growing importance thanks their capability of using tools and infrastructures already available for humans. Furthermore, their similarity with humans allows people to better understand the conditions, characteristics and limitations of the robot. In such a scenario, general users with no particular expertise in robotics will need to be able to teach motions to humanoid robots.
When humans teach movements to other humans, they often use touch to convey a lot of information in an intuitive way. This can be observed, for instance, in the case of sport coaches or dance instructors. In this research, in order to enable teaching humanoids in a similar way, the way in which humanoids should react when being touched was clarified.

研究分野： Robotics

キーワード： Humanoids　Touch　Human Robot Interaction

１．研究開始当初の背景

Robots are expected to become an integrant part of society in the near future. Among robots, humanoids present several advantages. First, their shape, resembling that of humans, will allow them to use tools and infrastructures already available to humans (1). Second, their similarity with human beings allows them to be easily understood by humans. People can easily recognize the activities they are performing, the conditions in which they are, and comprehend their physical limitations.

The usage of humanoids robots, however, presents some difficulties. Equipping the robots with the knowledge necessary to perform all possible tasks before delivering them to their end users is unfeasible.

On the other hand, automatic learning of new tasks from scratch when necessary is impossible. Indeed, the high number of degrees of freedom of humanoids leads to very highly dimensional continuous search spaces, over which solutions cannot be found in reasonable times.

If people are able to teach to the robot, however, new task can be learned in much shorter times (2).

One possible approach is to have the robot observe humans performing the task, and learn from the examples provided by the human (3). In many cases, however, users may want to teach the robot a task they are not able to perform themselves because of physical limitations.

In these cases, users must be able to teach the robot directly how to perform the task. Teaching to humanoids should be possible not only for roboticists, but also for final users with no specific robotics knowledge. Teaching should thus be intuitive.

Focusing on people teaching movements to other people, it is possible to notice how sport coaches and dance instructors are able to convey a lot of information in an intuitive way by simple touches. Adopting a similar approach is promising for letting people teach movements to humanoid robots.

However, while human learners can interpret the meaning of the teacher's touches intuitively without any difficulty, estimating the meaning that teachers associate to touches is very complex for robots. The meaning is context dependent, and often varies depending on the teacher.

Fig. 1 provides a simple example of the influence of the context. If a user presses the upper part of the leg when the robot is standing he or she could imply that the robot should bend the leg backwards. However, when the robot is squatting, the same touch on the leg could mean that the robot should bend its knees further.

No models that explain how robots should interpret the meaning underlying tactile instructions are available in current literature. The same lack of models can be observed for the case of human to human communication as well. This research is the first step in this direction. The results are expected thus to contribute both to the fields on human-robot and human-human tactile communication.

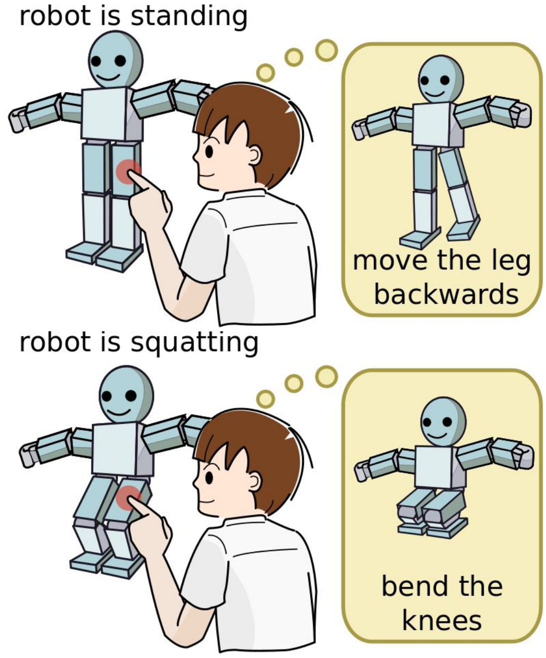

Fig.1 Example of context dependence of the meaning of tactile instructions.

(1)K. Yokoi, K. Nakashima, M.Kobayashi, H. Mihune, H. Hasunuma Y. Yanagihara, T. Ueno, T. Gokyuu and K. Endou, A Tele-operated Humanoid Operator, The International Journal of Robotics Research, 25(5), 593-602, 2006

(2)B.D. Argall, S. Chernova, M. Veloso and B. Browning, A survey of robot learning from demonstration, Robotics and autonomous systems, 57(5), 469-483, 2009

(3)T. Inamura, I. Toshima, H. Tanie and Y. Nakamura, Embodied Symbol Emergence based on Mimesis Theory, The International Journal of Robotics Research, 23(4), 363-377, 2004

２．研究の目的

This research aims at enabling users to communicate with humanoid robots through touch. In detail, this work focuses on letting people teach new motions to humanoids using tactile instructions. This is expected to enable general users, which do not have specific robotics knowledge, to teach new movements to humanoids in the same way sport coaches or dance instructors use physical interaction to teach their students how to move.
While human students are able to unconsciously interpret the meaning of tactile instructions, robots need to be equipped with a model that converts tactile instructions to movements.
This research focused on analyzing this kind of mapping between touches and movements that people expect from a humanoid robot.

３．研究の方法

In this work the kind of responses that people expect when they touch a humanoid robot were investigated. The robot used for the experiments is M3 Neony, a 22 DOF 50cm high humanoid robot equipped with tactile sensors over the whole body. The robot is shown in Fig.2.

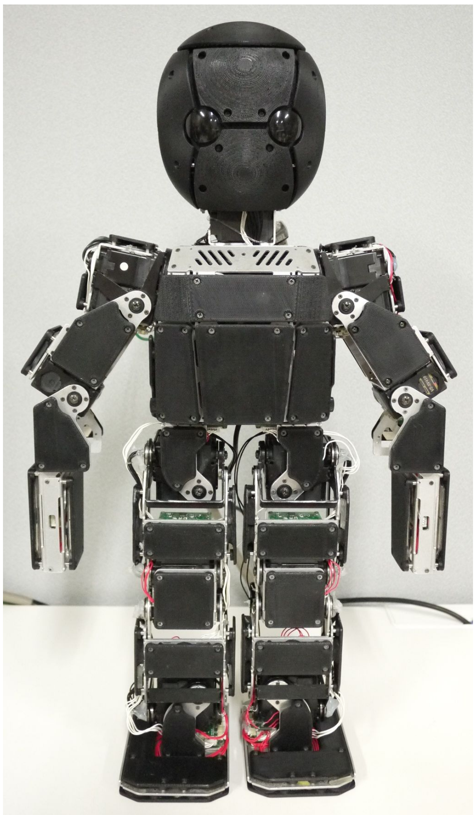

Fig.2 Humanoid robot used in the experiments.

As a first step, data on how people expect the robot to respond to the pressure on 90 different locations were collected. In total, over 1800 responses were collected from over 20 people.
In order to define the type of responses that are associated to touch, similar responses were clustered.
Different types of coding for the responses were analyzed, and a representation that provides high clusterability was identified using the Hopkins statistics.
This representation, based on a description of the final posture assumed during the movement in terms of 41 categorical variables, was used to cluster the responses using a Naive Bayes classifier.
Seventeen clusters, each corresponding to a different type of responses to touch, were identified. The meaning of each cluster was obtained by computing the Kullback Leibler divergence between the probability distribution of the variables in each cluster and the overall average distribution of the same variables.
The seventeen clusters can be roughly classified in six groups. The first group, comprising five clusters, consists of responses that are simple movements of a single limb. The second group, comprising two clusters, consists of protective movements, executed with the left hand or both hands. These responses were found to be associated mainly with touches on the upper body, which the participants likely considered more vulnerable.
The third, comprising four clusters, involves touching the touched part.
This is done using either hand, both hands, or hand movements associated with leg movements that resemble squatting.
The fourth group, comprising two clusters, consists of movements that appear to be directed at dodging the touch, either by twisting the body or sliding it.
The fifth group, comprising two clusters, consists of dodging behaviors performed with ample movements of the feet, associated with a twist of the body in a clockwise or counterclockwise direction.
The clustering, despite being done completely automatically, was shown to be in strong agreement with people's intuitive way of classifying responses, providing support to the fact that the automatically identified clusters correspond to a sound classification of robot’s responses to touch.

In practice, this was verified experimentally in the following way. Two responses from a cluster, and another response from another cluster, were selected randomly and presented to experiment participants with no particular robotic knowledge.
It was then asked them to choose the two responses among the three that they reputed the most close to each other.
In this way, it could be measured how often experiment participants replied that the two responses from the same cluster are more similar to each other than they are to the third response, i.e. how often the algorithm clustering and people's perception of response similarity do match.
Additionally, the classification algorithm was shown to provide indication on how much a response is typical and natural to the users. Specifically, the likelihood of a certain response to belong to one of the clusters, computed by the classification algorithm, was shown to be highly correlated with the degree by which general people perceive the response as natural.

４．研究成果

This research contributes the general paradigm of shifting current technology from a robot-centered setup, in which humans need to understand the robot's behaviors and adapt to them, to a human-centered setup, where robots integrate naturally into human activities.
The naturalness of interaction increases the effectiveness of robot usage by shortening the time required for teaching, reduces errors, and increases user acceptance in social contexts.
The contribution of this research consists in clarifying how robot should move when touched. With the increase in the frequency by which robots will come in close contact with humans, reactions to touch will assume great importance in the near future.
As a practical example, the analysis conducted in this research showed that many people expect that when robot is touched somewhere, it will watch the touched part. This kind of reactions may be used as an early notification of touch for increasing safety in the interaction. Other reactions identified by the proposed clustering algorithm may be used for motion teaching. Besides constituting the responses necessary for motion development, the identified responses may be used to provide feedback, helping users in not losing interest in teaching, and motivating them in putting more effort in the process. This, in turn will increases the possibilities of collecting a sufficient number of good quality demonstrations, and eases robot's learning.
Finally, the repertoire of reactions collected may be used as elements of the reactions used to express the internal state of social robots. For instance, some of the reactions may be good at expressing the robot's surprise to the touch stimulus, as well as the attitude toward being touched. More in general, the classification of naturally expected robots responses to touch identified in this research provide directions for the design of interactive robots equipped with tactile sensing capabilities.

５．主な発表論文等
（研究代表者、研究分担者及び連携研究者には下線）

〔雑誌論文〕（計　１件）

Fransiska Basoeki, Fabio Dalla Libera, Hiroshi Ishiguro, How do people expect humanoids to respond to touch?, International Journal of Social Robotics, 査読あり, Vol.7(5), 2015, pp. 743-765 , DOI:10.1007/s12369-015-0318-7

〔学会発表〕（計　０件）

〔図書〕（計　０件）

〔産業財産権〕
○出願状況（計　０件）

○取得状況（計　０件）

〔その他〕
ホームページ等
http://robotics.dei.unipd.it/~fabiodl

６．研究組織

(1)研究代表者
ダーラリベラ・ファビオ
（Dalla Libera Fabio）
大阪大学・基礎工学研究科・基礎工学研究科・特任助教(常勤)
研究者番号：８０７４００９２

(2)研究分担者

(3)連携研究者