Experimental Platform for Human Robot Interaction based on Human Motions

Praveenkumar Vasudevan[1] and Gentiane Venture[2]

[1] École Centrale de Nantes, Nantes, France,
`praveenv4k@gmail.com`
[2] Associate Professor, Tokyo University of Agriculture and Technology, Japan
`venture@cc.tuat.ac.jp`

Abstract. Humans interacting with intelligent robots has been seen as a potential game changer of the future. In scenarios where robots coexist with humans in a social environment, understanding not only verbal communication, but also non-verbal communication is extremely inevitable. The non-verbal communication carries information such as intention, emotion and health of a human, that adds value to the way robots participate in an interaction. Additionally, the people who design interaction scenarios are from diverse fields who do not essentially have the required robot programming skills. In this paper we propose an easy to use and intuitive programming paradigm which gives the power to design robot behaviors taking into account human motions. We propose a distributed architecture which gives the capability to plug and play multimodal motion recognition systems and diverse class of robots. We present results of Nao humanoid robot performing actions understanding human motions using kinect motion recognition system.

Keywords: human robot interaction, motion recognition, robot behaviors, kinect, nao

1 Introduction

Human-Robot interaction (HRI) has emerged as the most promising fields in the recent years owing to its immense potential in the fields of education, entertainment, elderly care and rehabilitation. HRI is a challenging research field at the intersection of psychology, cognitive science, social sciences, artificial intelligence, computer science, robotics, engineering and human-computer interaction[3]. Goodrich[5] in his extensive survey proposed two main types of HRI namely Remote interaction/ Tele-operation and Proximate interaction. The latter is particularly important where the humans and the robots are co-located (for example, service robots may be in the same room as humans). Proximate interaction has gained importance due to the successful encounters of putting robots to work with human beings. It has led to the development of a new class of robots called Social Robots. Fong et al. [4] define that social robots are able to recognize each other and engage in social interactions; Breazeal et al.[2] explain that a social robot is a robot which is able to communicate with humans

in a personal way; Bartneck and Forlizzi [1] describe that a social robot is an autonomous or semi-autonomous robot that interacts with humans by following some social behaviors; Hegel et al. [6] define that a social robot is a combination of a robot and a social interface. Summarizing all these Yan et al. [7] defines A social robot is a robot which can execute designated tasks and the necessary condition turning a robot into a social robot is the ability to interact with humans by adhering to certain social cues and rules.

The social robots already entered the human spaces as entertainers, educators[3] and caring agents[1]. Given that social robotics has emerged as a promising field, designing and developing interaction systems need to be approached in a systematic manner wherein the robots should be able to understand and interact with the environment (man and materials) in a better way. To make it possible it is necessary to develop robotic systems with essential cognitive skills for efficient and natural interaction. Most often the onboard sensors on the robots fail to satisfy this demanding requirement. Hence consideration of using exteroceptive sensors to this purpose is important.

The HRI designers are from diverse backgrounds. So the tools needed to design behaviors of a social robot should be intuitive and user friendly. However when it comes to designing complex behaviors, traditional flow chart based approaches[2] increase the cognitive load of the users as they have to hand tailor all the data flow and reactiveness. More efficient tools are needed which could tackle this issue.

The main contribution of this paper will be to develop an application independent experimental platform wherein a social robot will be equipped with essential perceptual ability to understand human motions. The behavior design of such a social robot will be made possible by efficient behavioral framework. The experimental platform will be used to design and evaluate the interaction between the social robot and the human.

2 Previous work

In this section, we will consider the case when the Hamiltonian $H(x)$ is autonomous. For the sake of simplicity, we shall also assume that it is C^1.

We shall first consider the question of nontriviality, within the general framework of (A_∞, B_∞)-subquadratic Hamiltonians. In the second subsection, we shall look into the special case when H is $(0, b_\infty)$-subquadratic, and we shall try to derive additional information.

The General Case: Nontriviality. We assume that H is (A_∞, B_∞)-subquadratic at infinity, for some constant symmetric matrices A_∞ and B_∞, with $B_\infty - A_\infty$ positive definite. Set:

$$\gamma := \text{smallest eigenvalue of} \quad B_\infty - A_\infty \tag{1}$$

$$\lambda := \text{largest negative eigenvalue of} \quad J\frac{d}{dt} + A_\infty . \tag{2}$$

Theorem 1 tells us that if $\lambda + \gamma < 0$, the boundary-value problem:

$$\dot{x} = JH'(x)$$
$$x(0) = x(T) \tag{3}$$

has at least one solution $\bar{x}$, which is found by minimizing the dual action functional:

$$\psi(u) = \int_o^T \left[\frac{1}{2} \left(\Lambda_o^{-1} u, u \right) + N^*(-u) \right] dt \tag{4}$$

on the range of Λ, which is a subspace $R(\Lambda)_L^2$ with finite codimension. Here

$$N(x) := H(x) - \frac{1}{2} \left(A_\infty x, x \right) \tag{5}$$

is a convex function, and

$$N(x) \leq \frac{1}{2} \left((B_\infty - A_\infty) x, x \right) + c \quad \forall x . \tag{6}$$

Proposition 1. *Assume $H'(0) = 0$ and $H(0) = 0$. Set:*

$$\delta := \liminf_{x \to 0} 2N(x) \left\| x \right\|^{-2} . \tag{7}$$

If $\gamma < -\lambda < \delta$, the solution $\bar{u}$ is non-zero:

$$\bar{x}(t) \neq 0 \quad \forall t . \tag{8}$$

Proof. Condition (7) means that, for every $\delta' > \delta$, there is some $\varepsilon > 0$ such that

$$\left\| x \right\| \leq \varepsilon \Rightarrow N(x) \leq \frac{\delta'}{2} \left\| x \right\|^2 . \tag{9}$$

It is an exercise in convex analysis, into which we shall not go, to show that this implies that there is an $\eta > 0$ such that

$$f \left\| x \right\| \leq \eta \Rightarrow N^*(y) \leq \frac{1}{2\delta'} \left\| y \right\|^2 . \tag{10}$$

Fig. 1. This is the caption of the figure displaying a white eagle and a white horse on a snow field

Since u_1 is a smooth function, we will have $\|hu_1\|_\infty \leq \eta$ for h small enough, and inequality (10) will hold, yielding thereby:

$$\psi(hu_1) \leq \frac{h^2}{2}\frac{1}{\lambda}\|u_1\|_2^2 + \frac{h^2}{2}\frac{1}{\delta'}\|u_1\|^2 \ . \tag{11}$$

If we choose δ' close enough to δ, the quantity $\left(\frac{1}{\lambda} + \frac{1}{\delta'}\right)$ will be negative, and we end up with

$$\psi(hu_1) < 0 \qquad \text{for} \ \ h \neq 0 \ \ \text{small} \ . \tag{12}$$

On the other hand, we check directly that $\psi(0) = 0$. This shows that 0 cannot be a minimizer of ψ, not even a local one. So $\overline{u} \neq 0$ and $\overline{u} \neq \Lambda_o^{-1}(0) = 0$. $\qquad\square$

Corollary 1. *Assume H is C^2 and (a_∞, b_∞)-subquadratic at infinity. Let ξ_1, $\ldots, \xi_N$ be the equilibria, that is, the solutions of $H'(\xi) = 0$. Denote by ω_k the smallest eigenvalue of $H''(\xi_k)$, and set:*

$$\omega := \text{Min}\ \{\omega_1, \ldots, \omega_k\} \ . \tag{13}$$

If:

$$\frac{T}{2\pi}b_\infty < -E\left[-\frac{T}{2\pi}a_\infty\right] < \frac{T}{2\pi}\omega \tag{14}$$

then minimization of ψ yields a non-constant T-periodic solution $\overline{x}$.

We recall once more that by the integer part $E[\alpha]$ of $\alpha \in \mathbb{R}$, we mean the $a \in \mathbb{Z}$ such that $a < \alpha \leq a + 1$. For instance, if we take $a_\infty = 0$, Corollary 2 tells us that $\overline{x}$ exists and is non-constant provided that:

$$\frac{T}{2\pi}b_\infty < 1 < \frac{T}{2\pi} \tag{15}$$

or

$$T \in \left(\frac{2\pi}{\omega}, \frac{2\pi}{b_\infty}\right) \ . \tag{16}$$

Proof. The spectrum of Λ is $\frac{2\pi}{T}\mathbb{Z} + a_\infty$. The largest negative eigenvalue λ is given by $\frac{2\pi}{T}k_o + a_\infty$, where

$$\frac{2\pi}{T}k_o + a_\infty < 0 \leq \frac{2\pi}{T}(k_o + 1) + a_\infty \ . \tag{17}$$

Hence:

$$k_o = E\left[-\frac{T}{2\pi}a_\infty\right] \ . \tag{18}$$

The condition $\gamma < -\lambda < \delta$ now becomes:

$$b_\infty - a_\infty < -\frac{2\pi}{T}k_o - a_\infty < \omega - a_\infty \tag{19}$$

which is precisely condition (14). $\qquad\square$

Lemma 1. *Assume that H is C^2 on $\mathbb{R}^{2n}\backslash\{0\}$ and that $H''(x)$ is non-degenerate for any $x \neq 0$. Then any local minimizer $\widetilde{x}$ of ψ has minimal period T.*

Proof. We know that $\widetilde{x}$, or $\widetilde{x} + \xi$ for some constant $\xi \in \mathbb{R}^{2n}$, is a T-periodic solution of the Hamiltonian system:

$$\dot{x} = JH'(x) . \tag{20}$$

There is no loss of generality in taking $\xi = 0$. So $\psi(x) \geq \psi(\widetilde{x})$ for all $\widetilde{x}$ in some neighbourhood of x in $W^{1,2}\left(\mathbb{R}/T\mathbb{Z}; \mathbb{R}^{2n}\right)$.

But this index is precisely the index $i_T(\widetilde{x})$ of the T-periodic solution $\widetilde{x}$ over the interval $(0, T)$, as defined in Sect. 2.6. So

$$i_T(\widetilde{x}) = 0 . \tag{21}$$

Now if $\widetilde{x}$ has a lower period, T/k say, we would have, by Corollary 31:

$$i_T(\widetilde{x}) = i_{kT/k}(\widetilde{x}) \geq ki_{T/k}(\widetilde{x}) + k - 1 \geq k - 1 \geq 1 . \tag{22}$$

This would contradict (21), and thus cannot happen. □

Notes and Comments. The results in this section are a refined version of [**?**]; the minimality result of Proposition 14 was the first of its kind.

To understand the nontriviality conditions, such as the one in formula (16), one may think of a one-parameter family x_T, $T \in \left(2\pi\omega^{-1}, 2\pi b_\infty^{-1}\right)$ of periodic solutions, $x_T(0) = x_T(T)$, with x_T going away to infinity when $T \to 2\pi\omega^{-1}$, which is the period of the linearized system at 0.

Table 1. This is the example table taken out of *The TEXbook,* p. 246

Year	World population
8000 B.C.	5,000,000
50 A.D.	200,000,000
1650 A.D.	500,000,000
1945 A.D.	2,300,000,000
1980 A.D.	4,400,000,000

Theorem 1 (Ghoussoub-Preiss). *Assume $H(t, x)$ is $(0, \varepsilon)$-subquadratic at infinity for all $\varepsilon > 0$, and T-periodic in t*

$$H(t, \cdot) \quad \text{is convex} \ \ \forall t \tag{23}$$

$$H(\cdot, x) \quad \text{is} \ T-\text{periodic} \ \ \forall x \tag{24}$$

$$H(t, x) \geq n\left(\|x\|\right) \quad \text{with} \ \ n(s)s^{-1} \to \infty \ \ \text{as} \ \ s \to \infty \tag{25}$$

$$\forall \varepsilon > 0 , \quad \exists c \; : \; H(t,x) \leq \frac{\varepsilon}{2} \|x\|^2 + c \; . \tag{26}$$

Assume also that H is C^2, and $H''(t,x)$ is positive definite everywhere. Then there is a sequence x_k, $k \in \mathbb{N}$, of kT-periodic solutions of the system

$$\dot{x} = JH'(t,x) \tag{27}$$

such that, for every $k \in \mathbb{N}$, there is some $p_o \in \mathbb{N}$ with:

$$p \geq p_o \Rightarrow x_{pk} \neq x_k \; . \tag{28}$$

$\square$

*Example 1 (*External forcing*).* Consider the system:

$$\dot{x} = JH'(x) + f(t) \tag{29}$$

where the Hamiltonian H is $(0, b_\infty)$-subquadratic, and the forcing term is a distribution on the circle:

$$f = \frac{d}{dt}F + f_o \quad \text{with} \; F \in L^2 \left(\mathbb{R}/T\mathbb{Z}; \mathbb{R}^{2n} \right) \; , \tag{30}$$

where $f_o := T^{-1} \int_o^T f(t)dt$. For instance,

$$f(t) = \sum_{k \in \mathbb{N}} \delta_k \xi \; , \tag{31}$$

where δ_k is the Dirac mass at $t = k$ and $\xi \in \mathbb{R}^{2n}$ is a constant, fits the prescription. This means that the system $\dot{x} = JH'(x)$ is being excited by a series of identical shocks at interval T.

Definition 1. *Let $A_\infty(t)$ and $B_\infty(t)$ be symmetric operators in $\mathbb{R}^{2n}$, depending continuously on $t \in [0, T]$, such that $A_\infty(t) \leq B_\infty(t)$ for all t.*

A Borelian function $H : [0, T] \times \mathbb{R}^{2n} \to \mathbb{R}$ is called (A_∞, B_∞)-subquadratic at infinity if there exists a function $N(t, x)$ such that:

$$H(t,x) = \frac{1}{2} \left(A_\infty(t)x, x \right) + N(t,x) \tag{32}$$

$$\forall t , \quad N(t,x) \quad \text{is convex with respect to} \; x \tag{33}$$

$$N(t,x) \geq n \left(\|x\| \right) \quad \text{with} \; n(s)s^{-1} \to +\infty \; \text{as} \; s \to +\infty \tag{34}$$

$$\exists c \in \mathbb{R} \; : \quad H(t,x) \leq \frac{1}{2} \left(B_\infty(t)x, x \right) + c \quad \forall x \; . \tag{35}$$

If $A_\infty(t) = a_\infty I$ and $B_\infty(t) = b_\infty I$, with $a_\infty \leq b_\infty \in \mathbb{R}$, we shall say that H is (a_∞, b_∞)-subquadratic at infinity. As an example, the function $\|x\|^\alpha$, with $1 \leq \alpha < 2$, is $(0, \varepsilon)$-subquadratic at infinity for every $\varepsilon > 0$. Similarly, the Hamiltonian

$$H(t,x) = \frac{1}{2}k \|k\|^2 + \|x\|^\alpha \tag{36}$$

is $(k, k + \varepsilon)$-subquadratic for every $\varepsilon > 0$. Note that, if $k < 0$, it is not convex.

Notes and Comments. The first results on subharmonics were obtained by Rabinowitz in [**?**], who showed the existence of infinitely many subharmonics both in the subquadratic and superquadratic case, with suitable growth conditions on H'. Again the duality approach enabled Clarke and Ekeland in [**?**] to treat the same problem in the convex-subquadratic case, with growth conditions on H only.

Recently, Michalek and Tarantello (see [**?**] and [**?**]) have obtained lower bound on the number of subharmonics of period kT, based on symmetry considerations and on pinching estimates, as in Sect. 5.2 of this article.

References

1. C. Bartneck and J. Forlizzi. A design-centred framework for social human-robot interaction. In *RO-MAN 2004. 13th IEEE International Workshop on Robot and Human Interactive Communication (IEEE Catalog No.04TH8759)*, pages 591–594. IEEE, 2004.
2. Cynthia Breazeal. *Designing Sociable Robots*. MIT Press, Cambridge, MA, USA, 2002.
3. Kerstin Dautenhahn. Methodology and themes of human-robot interaction: A growing research field. *International Journal of Advanced Robotic Systems, Vedran Kordic, Aleksandar Lazinica and Munir Merdan (Ed.)*, 2007.
4. Terrence Fong, Charles E. Thorpe, and Charles Baur. Collaboration, dialogue, human-robot interaction. In *Robotics Research, The Tenth International Symposium, ISRR 2001, Lorne, Victoria, Australia, November 9-12 2001*, pages 255–266, 2001.
5. Michael A. Goodrich and Alan C. Schultz. Human-robot interaction: A survey. *Foundations and Trends in Human-Computer Interaction*, 1(3):203–275, 2007.
6. Frank Hegel, Claudia Muhl, Britta Wrede, Martina Hielscher-Fastabend, and Gerhard Sagerer. Understanding social robots. In *Second International Conference on Advances in Computer-Human Interaction, ACHI 2009, February 1-7, 2009, Cancun, Mexico*, pages 169–174, 2009.
7. Haibin Yan, Jr. Ang, Marcelo H., and Aun Neow Poo. A survey on perception methods for humanrobot interaction in social robots. *International Journal of Social Robotics*, 6(1):85–119, 2014.