Ensuring Presence and Agency Through Precise and Responsive Full-Body Avatar Control

Eray Molla
IIG, I&C, EPFL

Abstract—Inverse Kinematics (IK) techniques are used to manipulate the posture adaptation of an articulated figure. In this paper a quick overview of the IK problem is presented and two methods belonging to different families of IK approaches, numerical and analytical, are introduced. After that, the use of IK and immersive interaction techniques are discussed on the treatment of phantom limb pain. Finally, the state of our research is summarized and the possible directions for our work are detailed.

Index Terms—Inverse Kinematics, Immersive Interaction, Virtual Reality Based Pain Treatment

I. INTRODUCTION

Inverse Kinematics deals with the control of the movement of an articulated rigid-body system, i.e kinematic chain. It is modelled as a hierarchy of segments, i.e. bones, and joints which connect the segments to each other like the articulations in human body. A posture is represented as a chain of joint transformations \( \theta \) which are expressed relative to their parent segments.

Some points attached to this hierarchy are identified as end effectors. The state (position, orientation etc.) of an effector is estimated by concatenating the joint transformations:

\[ x = f(\theta) \]  

(1)

where \( x \) denotes the state of the end effector and \( f \) is referred as forward kinematics function. In contrast to forward kinematics, inverse kinematics focuses on finding \( \theta \) for obtaining a convincing posture given a set of goal states of the end effectors:

\[ \theta = f^{-1}(x) \]  

(2)

where \( f^{-1} \) is the IK function. In literature, these goal states are commonly referred as either constraint, or, equivalently, task.

By relying on Eq. 2, we can designate IK as a constrained optimization problem. The constraints used for postural control of a virtual humanoid vary depending on the problem context. Most common ones are position, orientation, gaze and balance constraints. These constraints are based on the equality of the state of an end effector. Furthermore, inequality constraints are required to tackle some goals such as collision avoidance and joint limits.

It is frequent that finding a posture fulfilling all the constraints at the same time is impossible. To deal with conflicting constraints two common approaches have been proposed in the literature. The first set of methods \cite{3, 4} relies on assigning weights to the tasks in proportion to their relative importance. They try to minimize a weighted sum of constraint satisfaction errors. However, none of the constraints is exactly verified. The second type of approaches \cite{5} assign priorities to constraints. These methods aim at achieving more important tasks first. A task is resolved only if all the higher important tasks have already been satisfied.

Although analytical IK solutions exist for kinematic chains with few degrees of freedom (DOF), such techniques are not suitable for complex redundant systems like full-postural control of the humanoids. However, due to their low computational cost and simplicity, analytic IK methods are employed for providing solutions to a subset of the articulated structure when possible. In particular, analytical IK techniques for human limbs have been exploited by several authors \cite{6, 7, 8}.

For more complex redundant systems, Numerical IK techniques leading simultaneous resolution of DOFs are used. Such methods consider the IK problem as a cost function to be minimized thus solve it by using non-linear optimization procedures exploiting the Jacobian. Even though they provide
a general solution to IK problems, they are costly and may fall into local minimas.

In the following section, first, the basic Jacobian based formulation of IK is introduced. Then, we show how it can be extended to be able to handle the satisfaction of a second, possibly conflicting, constraint with less priority simultaneously. Finally, Baerlocher’s [5] algorithm which can deal with an arbitrary number of strict priority levels is discussed.

II. JACOBIAN BASED IK

Equation 1 can be linearized by exploiting the Jacobian matrix, \( J \). Note that the elements of \( J \) are instantaneous velocities of the end effectors. Then, the inverse of \( J \) is used as a local approximation of equation 2:

\[
\Delta \theta = J^{-1} \Delta x
\]

And, equivalently:

\[
\Delta x = J \Delta \theta
\]

Therefore, we can see \( J \) as a transformation from the posture variation space to the constraint variation space.

IK problems are usually highly redundant, i.e. \(|\theta| \gg |x|\), thus pseudo-inverse, \( J^+ \), and transpose of \( J \), \( J^T \) are used for optimization. \( J^+ \) is mostly preferred, because it ensures the smallest posture variation for the desired constraint variation (see Fig.1).

A. Handling a second priority

Any posture variation vector, \( \Delta \alpha \), belonging to the Null space, \( N(J) \), of \( J \) has no effect on the resulting constraint variation vector, since it is mapped to a Null vector by \( J \). This property has an important practical use, since it allows us to optimize a second constraint simultaneously without violating the satisfaction of the higher priority task.

By definition of \( J^+ \), \( P_{N(J)} = I - J^+ J \), defines an \( n \times n \) orthogonal projection operator to the Null space, \( N(J) \), of \( J \). Then, we can reformulate the problem as follows:

\[
\Delta \theta = J^+ \Delta x + P_{N(J)} \Delta \alpha
\]

Note that additional \( P_{N(J)} \Delta \alpha \) term has no effect on \( \Delta x \). The next step is to derive a methodology for choosing \( \Delta \alpha \) to verify both tasks in an efficient way. For doing that, we must consider the fact that the first term may interfere the satisfaction of the second task due to the postural variation it introduces. Therefore, this postural variation should be compensated in the constraint variation space of the second priority level:

\[
\Delta x_{2\theta_1} = J_2 (J_1^+ \Delta x_1)
\]

Hence, the contribution needed thanks to the \( J_2 \) is (see Fig. 2):

\[
\tilde{\Delta} x_2 = \Delta x_2 - \Delta x_{2\theta_1} = \Delta x_2 - J_2 (J_1^+ \Delta x_1)
\]

Finally, \( \tilde{\Delta} x_2 \) must be restricted to the Null space of \( J_1 \). This can be done by directly projecting \( J_2 \) with \( P_{N(J)} \):

\[
\tilde{J}_2 = J_2 P_{N(J)}
\]

This results in the following equation for \( \Delta \theta \) (see Fig. 3):

\[
\Delta \theta = J^+ \Delta x_1 + (J_2 P_{N(J)})^+ (\Delta x_2 - J_2 (J_1^+ \Delta x_1))
\]

B. Extension to P priority levels

Baerlocher et al. [5] introduced an algorithm which can resolve any number of strict priority levels. It relies on handling priorities in a recursive way by generalizing Eq. 9. The main idea is that when resolving a new priority level, cumulative contribution of the postural variations introduced by higher
priority levels is taken into account. In addition, in order not to violate any of the higher priority constraints, the solution is restricted to the Null space of the Augmented Jacobian Matrix, \( J_i^A \), which is basically a partitioned matrix formed recursively (see Fig. 4), where \( N(J_i^A) = N(J_1) \cap N(J_2) \cap N(J_3) \cdots \cap N(J_{i-1}) \). As a result the postural variation contribution at a new priority level is estimated by the following formula:

\[
\Delta \theta_i = (J_i P_{N(J_{i+1}^A)})^+ (\Delta x_i - J_i \Delta \theta_{i-1}).
\]  

(10)

where \( \Delta \theta_0 = 0 \) and \( P_{N(J_{i+1}^A)} = I_{n \times n} \).

When all the priorities are achieved, if there is still some remaining redundancy, an additional task can be added to the system. Hence, total postural variation is given as

\[
\Delta \theta = \sum_{i=1}^{p} \Delta \theta_i + P_{N(J_p^A)} \Delta \alpha
\]  

(11)

One key contribution of this method is that it also allows the computation of \( P_N \) in an incremental way:

\[
P_{N(J_p^A)} = P_{N(J_{p-1}^A)} - (J_i P_{N(J_{i+1}^A)})^+ (J_i P_{N(J_{i+1}^A)})
\]  

(12)

Such iterative estimation of projection operators reduces the algorithmic complexity of the operation from \( O(p^2) \) to \( O(p) \).

C. Addressing Joint Limits

Joint limits are considered as inequality constraints. When a joint limit violation occurs, this joint is clamped to its limiting value. \( \Delta \theta_0 \) is initialized by taking this violation, \( \beta \) into account, \( \Delta \theta_0 = \beta \), and the problem is solved one more time, but, without modifying the state of that joint.

D. Handling Singularities

Singularities happen when the required rank to carry out a task is less than the rank of the Jacobian matrix. (Please refer to Fig. 6 for an example case.) It means that given that configuration of the problem pure Jacobian based solution can not progress more. Instability issues occur in the vicinity of singular configurations. Singular Value Decomposition (SVD) is used to identify this problem clearly:

\[
J = \sum_{i=1}^{r} \sigma_i u_i v_i^T
\]  

(13)

where \( J \) is a Jacobian matrix of rank \( r \). And, by definition of the pseudo-inverse of \( J \):

\[
J^+ = \sum_{i=1}^{r} \frac{1}{\sigma_i} v_i u_i^T
\]  

(14)

Therefore, \( \sigma \) values around zero result in solutions with very big norms, i.e. quick postural changes, and thus cause stability issues. A traditional approach, [10], to deal with such degenerate cases is to make use of a damping coefficients which offers a smooth convergence about zero singular values:

\[
J^{+\lambda} = \sum_{i=1}^{r} \frac{\sigma_i}{\sigma_i^2 + \lambda^2} v_i u_i^T
\]  

(15)

Hence, to deal with possible singularity issues we modify Equation 10 as follows:

\[
\Delta \theta_i = (J_i P_{N(J_{i+1}^A)})^{+\lambda} (\Delta x_i - J_i \Delta \theta_{i-1}).
\]  

(16)

E. Discussion

In this section, we presented a prioritized IK algorithm handling any number of strict priority levels proposed by Baerlocher et al. [5]. Pseudo-code version of the algorithm by combining all blocks introduced so far can be seen on Figure 5. It provides a powerful mechanism to deal with conflicting requirements by handling them step by step as a hierarchy of prioritized tasks. It allows the contribution of any joint for resolving the constraints. Although, this might result in suffering from more local minimas due to the greater solution space it offers, it is noted that the hierarchical structure of priorities can help avoiding this situation. Because, each priority level introduces new limitations in the solution space and thus channels the algorithm towards the convergence.

In contrast to weighting strategy, it does not allocate resources to relatively less significant tasks unless all the higher priority tasks have been achieved. This behaviour makes the approach computationally more efficient. It, also, allows enforcing the satisfaction of visually important tasks first.

On the other hand, such an approach is too costly in compared to simple analytical solutions. It is less reliable since it does not guarantee the convergence to the global optimal solution. Moreover, due to its nature, it has a local view of the solution space: It does not consider alternative solutions and make a preference.

Before passing to the next section, a specific difficulty should be pointed out. A local singularity occurs in case of full extension of the human limbs. The problem is depicted on Fig. 6. In such a local singularity, the limb is locked and cannot contribute to the solution even if a solution exists. Although, damped least square pseudo-inverse method guarantees that the norm of the solution vector remains bounded, it results in a very slow convergence. As an alternative, thanks to the
synergistic fashion of the approach, other body parts of the body can contribute to the solution and convergence may happen. However, this is, obviously, less favorable than simply flexing the arm and offering a local solution. This problem has already been addressed by Boulic et al. [11].

In the next section, we analyze the research work of Kallmann [8] in which he proposes an algorithm for full body reconstruction by using Analytical IK.

III. ANALYTICAL IK WITH BODY POSTURE CONTROL

Kallmann [8] introduced a full-body analytical IK algorithm relying on the solution of the well-known seven degrees of freedom (7-DoF) limb model and keyframe interpolation for reconstructing the rest of the body posture. His method is mainly suitable for animating reaching tasks guaranteeing exact position and orientation of the hands. In this section, first, an introduction to the 7-DoF limb problem is presented and an IK formulation based on swing-and-twist parameterization [12] is derived. Then, we proceed to the full-body scenario.

A. Analysis of 7-DoF Limb Problem

The limb model which is commonly used by the IK community is composed of two segments controlled by three joints similar to the limbs of humans. In the rest of this discussion, these joints will be referred to as base joint, i.e. shoulder or hip; mid, i.e. elbow or knee; and end, i.e. wrist or ankle. The base is parameterized as a ball-and-socket joint with 3-DoF, mid joint is a joint with 2-DoF controlling the flexion and the twist of the lower limb. Finally, the end is a 2-DoF swing joint.

All of these joints have their own local coordinate systems (CS), called anatomical frame, where, by convention, \( z \) axis is aligned with the segment that they control. This axis also defines the axis of the twist rotation, if applicable. For choosing \( x \) and \( y \) axes, different conventions can be used according to the characteristics of the problem. The derivations we introduce assume that the problem is solved for the right arm case where \( y \) axis is aligned with positive up vector in the default arm posture for the right arm (see Fig 7).
6-DoF; however, the limb configuration is controlled by 7-DoF. This introduces a 1-DoF redundancy. From a practical aspect, the problem can be deemed as follows. When the base and end joint positions remain fixed, the mid joint is still able to orbit about a circle. In the literature, this degree of freedom is referred as swivel angle and controls the position of the mid joint on the circle (see Fig. 8).

![Fig. 8. Swivel angle (Φ) and mid-flexion (Θ). n is the normal of the circle where elbow can orbit. u is a vector to parameterize the positions on the circle, by convention, chosen as the projection of −y of the global CS on the circle. B, M and E are base, mid and end joints, respectively, and C is the center of the circle.

Hence, the position of the mid joint can be parameterized with swivel angle as follows:

\[ \hat{M} = \hat{C} + r(\hat{u}\cos\phi + \hat{v}\sin\phi) \]  

(17)

where \(\hat{v} = \hat{n} \times \hat{u}\) and \(r\) is the radius of the circle.

1) Mid Flexion: We start to solve for joint angles from mid flexion. As can be seen on Fig. 8, B, M and E forms a triangle whose edge lengths are already known, even if the exact position of M is not known. Therefore, \(\hat{M}\) can be estimated via cosine theorem. Note that, flex angle (\(\Theta = \pi - \hat{M}\)).

\[ \Theta = \pi \pm \arccos\left(\frac{d_1^2 + d_2^2 - |e|^2}{2d_1d_2}\right) \]  

(18)

where \(d_1\) is the length of the upper limb, \(d_2\) denotes the lower limb length and \(|e|\) is the distance between the shoulder joint and the desired position of the end joint. Please note that, only the sign with negative value of the second term is valid due to the parameterization presented here.

2) Base Swing: The goal of the base swing rotation is to bring the mid joint from its default position to its desired position, \(\hat{M}\) without causing any twist about \(\hat{z}\) so that the twist required can be estimated separately. This can be achieved by a direct rotation whose axis is \(\hat{z} \times \hat{M} / |\hat{z} \times \hat{M}|\). And the angle of rotation is the one lying between \(\hat{z}\) and \(\hat{M}\): \(\arccos\frac{\hat{z} \cdot \hat{M}}{d_1}\). Hence the swing rotation required is given in angle-axis format as follows:

\[ s_1 = \frac{\hat{z} \times \hat{M}}{|\hat{z} \times \hat{M}|} \arccos\frac{\hat{z} \cdot \hat{M}}{d_1} \]  

(19)

3) Base Twist: Assume that base swing and mid flex are applied on the limb. This brings the end joint onto the same circle as its target position whose normal is \(d_1\). Therefore, the signed angle between the projections of those vectors on the plane where the circle lies gives the twist which should be applied as depicted on Fig. 9.

4) Mid Twist and End Swing: By concatenating the rotation that we estimated so far, the initial state of the end joint coordinate frame can be found:

\[ q_e = q_{bs}q_{bt}q_{mf} \]  

(20)

where \(q_{bs}, q_{bt}\) and \(q_{mf}\) are the quaternions representing estimated base swing, base twist and mid flexion rotations, respectively. Let \(q_{bt}\) denote the target orientation of the end joint. We can estimate the rotation that the mid twist and end swing has to achieve by estimating the relative rotation between \(q_e\) and \(q_{bt}\):

\[ q_e = q_{mf}q_{bs} = q_e^{-1}q_{bt} \]  

(21)

where \(q_e\) denotes the relative rotation. Please note that, even though mid twist and end swing are applied on different joints their combined effect is exactly like a single 3-DoF rotation. Hence, these rotations can be estimated by simply decomposing \(q_e\) into its swing and twist components.

5) Determining Swivel Angle: Swivel angle is determined in an iterative way. It is selected in order to avoid joint limit violations and collisions. The search procedure starts from a feasible value, i.e 30° and looks for a valid angle by incrementing and decrementing \(\phi\) with small values. It is restricted into a range for efficiency reasons. Once a legal value is found, the search procedure stops. If there is no valid solution in the search range, failure is reported.

B. Handling Body Posture

Body posture control relies on blending the pre-designed key postures. These key postures are stored in relation to the shoulder swing required to align the upper limb to a target position. Let \(\beta\) be the positional constraint to place a hand and \(\vec{B}\) denotes the base joint position. Then, \((\vec{p} - \vec{B})\) is the direction where the upper limb should be aligned to. The required shoulder swing rotation, \(s_1\), in axis-angle representation, determines the resulting body posture. In other words, it designates a map between 3D relative end effector positions and body posture representation plane. Hence, a body
behavior, $P$, defined by $n$ alternative postures is designated as follows:

$$P = \{(s_1, p_1), (s_2, p_2), \cdots (s_n, p_n)\}$$

(22)

where $s_i$ is a point on the shoulder swing plane and $p_n$ is the joint states defining a posture. Please note that, if the simultaneous control of both hands are required two separate arm and leg configurations form a double cone. Intersection of this double cone with the objects in the environment gives the invalid positions. The line segments can be extended to cylinders.

As pointed out before, Virtual Humanoids and IK are essential for several domains. In the following section, we analyze the use of IK on a domain based application.

IV. VR BASED PAIN TREATMENT

A. Phantom Limb Pain and Mirror Box Therapy

Following amputation, the loss of a limb, people usually experience vivid sensations on their absent body part as if it is still present. In majority of cases, this is a painful experience known as phantom limb pain [13]. Amputees suffer from severe pain and this may even limit their daily lives. Several methods have been proposed for its treatment; however, most of them have been reported as inefficient [14].

One notable success has been achieved by Ramachandran et al. where they developed a device, called mirror-box, for appropriate visual input manipulation [15]. This device is a simple box which is vertically divided into two by a mirror. The patient places his limbs, both the intact and absent ones, into the box and the top of the box in the side of the phantom one is covered, while the top of the other side is removed. Therefore, the reflection of the remaining limb on the mirror superimposes the felt position of the phantom limb in the participants visual field as can be seen on Fig. 11. When the intact limb is moved, this creates a visual illusion such that the patient feels like the amputated limb is moved, too, so, the pain is reduced.

Despite its considerable contribution, some limitations of mirror box therapy have been pointed out [16]. For instance, during the therapy, the participant has to keep his intact limb into the constrained space of the box. Moreover, the viewpoint and the head direction can have only subtle changes.

$$w_p = k \frac{d^2}{a^2}$$

(24)

where $k$ is a coefficient near 1, and $w_{p_{\text{init}}} = 1 - w_p$.

When the body posture is determined, analytical IK method introduced in Section III-A is used to reconstruct the arms. Note that both legs are reconstructed in the same way to ensure they remain at their initial locations.

C. Discussion

In this section a full-body IK relying on analytical IK techniques has been presented. The key body postures are organized as a function of shoulder swing and an interpolation scheme is used to determine the resulting body posture. Analytical 7-DoF limb model solver is used for arm and leg reconstruction. Such a technique is very suitable and reliable for reaching tasks. However, it does not propose postural control with arbitrary types of constraints even though it deals with collision detection.

The main advantages of the method are its simplicity and low computational cost due to the use of analytical techniques, but, it can be sped up even further. Obviously, the swivel search forms the bottleneck of the system since it requires an iterative check for finding a valid angle. However, this can also be solved analytically as Korein [6] suggests by finding all valid swivel angles. Please note that in our recent submission to JVRC\(^2\) we also addressed this problem by deriving formulations using spherical polygon geometry, quaternion algebra and swing-twist parameterization. Author claims that this search procedure is mainly needed for collision avoidance, but, this can also be addressed without requiring iterations (see Fig. 10).

![Fig. 10. Collision avoidance for 7-DoF arm model [6]. Assume that upper and lower limbs are simple line segments then combination of all possible configurations form a double cone. Intersection of this double cone with the objects in the environment gives the invalid positions. The line segments can be extended to cylinders.](image-url)
since the patient has to stay focused on the mirror. To deal with such limitations, several experimental setups relying on augmented (AR) \cite{17, 18} and virtual reality \cite{19, 20} have been proposed.

### B. AR and VR Based Phantom Limb Pain Rehabilitation

O’Neill et al. \cite{17} and Desmond et al. \cite{18} used a data glove and magnetic sensors to capture the motion data of the intact arm and transposed them to animate a virtual arm rendered on a flat screen positioned like a mirror. This results in an illusion similar to the mirror box therapy. Furthermore, their system provides an option for moving the virtual arm in the same direction as the remaining anatomical arm, instead of mirroring joint angles.

Cole et al. \cite{19} tracked the movement of the remaining portion of the amputated limb, stump, rather than the contralateral one, to drive the virtual one. A major advantage of this system is that it does not require tasks based on bilateral movements. Moreover, since the actions on the one side of the body are driven by the opposite side of the brain, the correct hemisphere of the brain is involved in the therapy. They designed two types of tasks for amputees. The first one requires reaching, grasping, retrieving and replacing an apple on a table. The second task was designed for lower body amputees where they are supposed to press the pedal of a drum with their virtual limb.

Murray et al. \cite{20} came up with a similar experimental setup to O’Neill’s work \cite{17} where the captured joint angles of the intact limb are mirrored to the contralateral one for postural reconstruction in the virtual space. However, they used a head-mounted-display (HMD) for better immersion and sensors for head tracking. Moreover, their system provides a visual representation of the whole body as from a first person perspective (see Fig. 11). They used tasks such as placing the virtual limb onto some targets, batting or kicking a ball.

### C. Discussion

It is clear that the use of VR contributes to resolve the limitations of the mirror box therapy pointed out above. O’Neill et al. \cite{17} and Desmond et al.’s \cite{18} systems are still subject to the space limitation for the tasks since the patient has to remain in front of the screen. Murray and his colleagues \cite{20} system helps to release this constraint by the use of an HMD; however, it is too cumbersome for such sensitive patients. Furthermore, controlling a mirrored virtual arm does not seem intuitive. Cole et al.’s setup allows the patient to control a virtual one on the same side of the phantom one. However, it is not applicable for the patients whose amputated limb’s remaining portion is paralyzed or does not exist.

### V. Research Proposal

#### A. Current State of Our Work

We designed a tool which facilitates skeleton and marker calibration for Motion Capture process. This tool allows the edition of the bone lengths and customizing the posture of the virtual character to fit it to the performer.

We provided a 7-DoF analytical IK solver. We also derived a closed form solution for parameterizing biomechanically meaningful joint limits as swivel angle intervals relying on spherical polygon geometry, swing-twist parameterization and quaternion algebra. We came up with a simple technique for capturing the motion of the clavicle. We submitted a poster to JVRC titled as “Biomechanically Valid Arm Posture Reconstruction Exploiting Clavicle Movement”.

![Fig. 11. Left: Mirror box therapy. Right: A user immersed by Murray et al.’s system. Images have been retrieved from \cite{21}.
](image)

In the above proposal, we aimed to contribute to the control of the articulated structures in real time by allowing fluid interactions with cluttered virtual environments. Of course, virtual humanoids are of our highest interest.

### B. Future Work

The key focus of this proposal is to contribute at the control of the articulated structures in real time by allowing fluid interactions with cluttered virtual environments. Of course, virtual humanoids are of our highest interest.
We will, first, investigate some known issues with the analytical IK methods. They are designed to take advantage of only a limited number of DoF like in the case of analytical limb solution. For instance, there might not be any valid swivel angle value for a given limb IK problem satisfying the constraint due to the joint limits and collisions. In such a case analytical algorithm simply fails. This, in particular, happens in cases where collision is frequent. Therefore, it is inevitable to benefit from redundancies available in other parts of the hierarchy for achieving such a task. Exploration and exploitation of such available redundancies will be our first point to address.

We will also explore the techniques to speed-up the convergence process of Baerlocher’s work. One foreseen solution is to embed the analytical limb solution to this architecture in a transparent way. Boulic et al. [11] already showed that integrating an analytical constraint to that framework is possible by proposing a solution to, so called, the flexing blindness syndrome. The convergence speed can also be reduced by analysing the problem structure for anticipating any possible issues which may avoid fast convergence. For example, joint limit violations cause losing the redundancy provided by that joint. Anticipating such problematic issues and avoiding it are presumed to improve both convergence speed and its quality.

One line of research will be dedicated to increase the quality and the complexity of the interaction with the virtual environment. There are two possible directions to contribute in this context. Peinado et al. [23] offered a technique for anticipation and avoidance of collision. However, this work is not addressing the class of concave obstacles. Interaction with this type of objects will be explored. Second, we will investigate “region reaching goals” [22] for better modelling human behavior. This work is based on the idea that positional goals can be relaxed to region goals to reproduce human behavior with a reduced complexity. The proposed methods in this context either rely on a transposed Jacobian [22] thus they do not deal with an arbitrary number of priority levels, or, do not offer interactive performance [24]. We will address these shortcomings.

We will keep on working on the VR based pain treatment methods. A detailed empirical study needs to be done for assessing both our current system’s efficiency for reducing the pain and its usability. Thanks to our collaboration with the doctors from Morges Hospital, we are about to start a pilot study. For the time being, we focus on phantom limb pain phenomenon, but, the scope of this research work can be extended to other types of pain rehabilitation like surgeries restricting the mobility of the limbs. Such a direction to our research is a good basis to evaluate the usability improvement of our IK algorithms since it requires full body interaction with the virtual environment for real use case scenarios.

REFERENCES


