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Fitting teleoperation and virtual reality technologies towards teleworking

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Abstract

One of the most challenging purpose for multimedia systems is to include haptic data exchange through computer network. This possibility may allow 'hard' teleworking i.e. touching and manipulating real or virtual remote features, thus changing physical properties of remote locations. This paper discusses this topic based on the well known teleoperation technology while being enhanced using virtual reality techniques. A teleworking frame experiment highlighting the proposed ideas is presented.

1 Introduction

Remote data processing through computer networking has known a considerable progress. A great part of this progress is devoted in the matter of world wide web computing using advanced communication means and protocols such as Internet. Meanwhile, virtual reality technology (VR) is renewing man-machine interfaces using refined control and feedback to allow user-friendly interfaces involving all human sensory capabilities [1].

It is also becoming evident that due to some scientific, technological, sociological and economical evolution aspects, the Man[1] of the future might be 'constrained' to adapt and/or adopt a different working style. Allowing remote work or teleworking is such an eventual adaptation. This novel style is actually considered and many developed countries started to plan it seriously.

In this paper, it is suggested that teleworking is concerned by the mixture of the following two items:

1. the one which is actually actively used by means of remote computer data processing, see table 1[2]. Moreover its through-put is also constantly increasing to support multi-media sessions involving audio, video, 3D graphics and textual data exchange in the form of interactive communication with new applications in tele-conferencing, tele-medecine, tele-education, etc.

Year	France	USA
1988	1.000	10.000
1997	16.000	345.000
2005	500.000	6.500.000

Table 1: Teleworking stakes.

2. the second one is physical remote work. It consists in controlling devices, tools, machines at a distance. Those remote 'individuals' may interact haptically[3] with their environment and might modify it. It is well known to be teleoperation [10] [9], but this concept has been actually modernized [8].

This paper is focused on the second item, namely teleoperation adaptation to fit a friendly-using 'hard' teleworking. In the robotics field, a strong renewal of interest concerning the teleoperation control mode is actually noticed. In order to make a link with remote working style motivations, the reasons of teleoperation revival can also be considered as:

• scientific and technological; which arises from the difficulty to make autonomous robots in term of auto-decision making and; the emergence of new technlogies such as virtual reality, high-speed networking, etc.

• sociological, coming from the well known human-machine relation research problem, as for to fill the lack of haptic exchange in the nowadays used mltimedia systems.

[1] Is not meant to be gender-specific.
[2] Source: Ovum cabinet (GB)
[3] The word haptic includes both kinesthesia (force) and tactile data.

• economical, the need to control remote machines at a distance. This aspect join the sociological one when the remote environment is hostile to Man (space, nuclear dismentling, oceans ...).

In this paper, the adaptation of teleoperation and virtual reality technologies to fit teleworking is discussed. The proposed architecture is based on a novel telemanipulator architecture which has been called the hidden robot concept [6] [7]. A high level abstraction interface is being developped to allow remote control and feedback in order to ease the command of complex remote machines such as robots. An experiment highlighting the feasibility of the proposed scheme is presented in the last part of the paper.

2 Teleworking requirements

The problem involved by 'hard' teleworking is that in many application cases a simple operator 'teletransportation' in terms of telepresence is not possible. Indeed, teleworking imply obviousely a remote additional device or individual (both will be called the *performer*) to execute and carry-out the master operator actions. For instance, in telesurgery application, the master operator is the surgeon. The latter operates using surgical tools which obviousely need a performer to be manipulated at any remote site (a remote operation room). Hence, two extrem design schemes are:

1– the performer is another surgeon. In this case the master surgeon's actions can be seen as instructions chaining to be performed by the remote located surgeon. The feedback concerns the interpretation of the remote surgeon's vocal remarks and some images of the operated patient. Here the master device is simple: microphone, camera, keyboard, graphics, etc.

2– the performer is a kind of surgical robot without any autonomy. In this case the master actions are rather manual occuring at the very low level. By low level, it is meant that the surgeon must guide the robot since the surgical act is made by the adequate tool but through robot guidance. The feedback here, must occur at a very low level aswell. Indeed, the surgeon must feel on-line haptic and visual data which are issued from the interaction between the held tool and the operated patient. The master is generally a mechatronic device used to control the robot including other interfaces like cameras...

Between the two above cited cases, a large kind of performers combinations can be conceived and designed. However, the important point to notice is that the control and the feedback depends on the autonomy capacities of the remote performer. It is also to be noticed that in any case, the robot and/or another surgeon behavior is apriori unknown to the master surgeon. Especially since the surgeon is not necessarily a roboticist.

In fact, the two cases seem to be not adequate. In the first, a whole autonomy might be not secure, since the performer (remote surgeon) may interpret and use a different skill of the master one. This is not forbiden under reserve of the task success. In the second case, assuming that the surgeon is familiar to robots, the additional interface (robot) used to carry the tool will obviousely interfere on the transparency and on skill transfert in terms of surgical actions.

The technology which allows the modification of a remote environment by a device located there is known to be teleoperation. In a classical teleoperator[4], haptic feedback is of a primary issue. The exchange of haptic information between the master and the slave robot is done through power transfert, namely, a bilateral control coupling between the master and the slave by the exchange of flux and effort parameters. The main performance characterizing any teleoperator is: (i) obviousely its stability and (ii) the transparency quoted in term of the relialibility of operator command reproduction through robot action and, robot action transfert into operator perception, through feedback.

Fitting teleoperation to teleworking requires however to take in charge additional inter-related constraints such as:

- widen its use to non-specialized persons by its extension to many application areas.
- design of user-friendly control and feedback interfaces which provide necessary feedback in such a way to be processed by the operator in a natural, intuitive manner.
- create systems that can rather cooperate through adequate flexible architectures between the master and the remote individuals for a task target achievement.
- hide or handle the complexity of the remote located device (performer) and the master interface to ease the control (teleworking) and, to allow whole operator skill transfert, without overloading additional constraints when this is possible.
- take in charge time-delay and its eventual fluctuations.

[4]Teleoperation system and/or architecture.

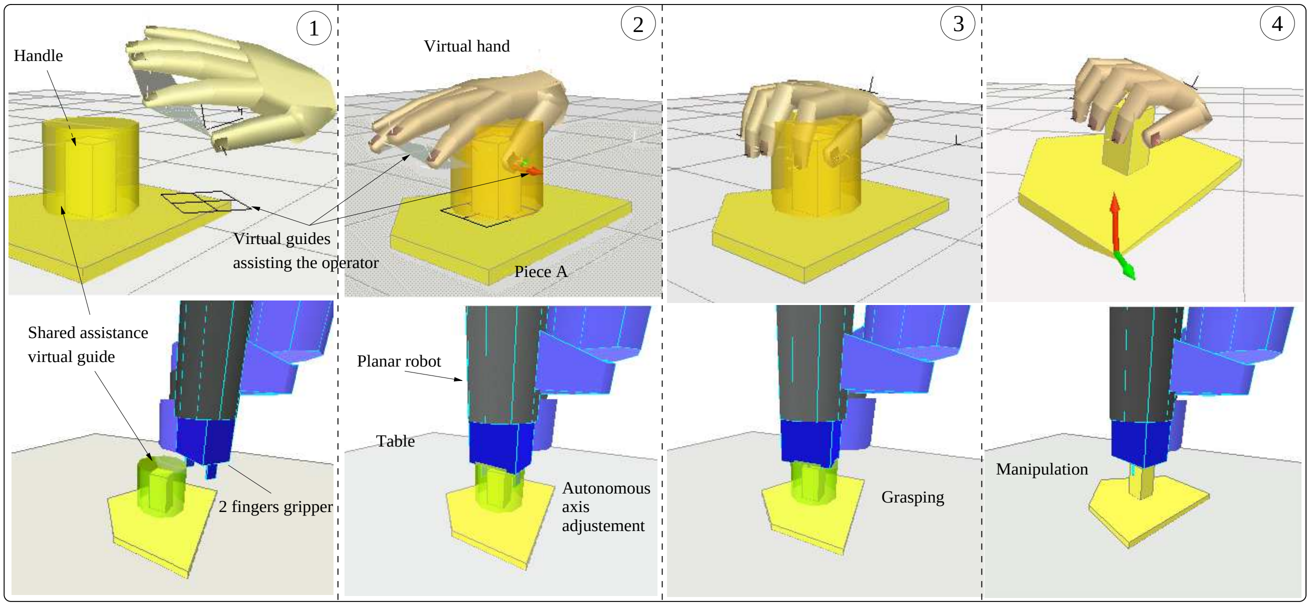

Figure 1: *Virtual task achievement. Illustration of direct operator actions transformations into robotics actions.*

3 The proposed teleworking architecture

According to the previousely quoted constraints, a teleworking architecture is proposed to be an astute fitting of what has been performed in a special teleoperation scheme using virtual reality [7].

3.1 Intermediary functional representation (IFR)

As the performer might be complex and not necessarily well known of the master operator, it may affects transparency or create barriers to whole operator skill transfert. Thus a whole virtual or augmented reality is suggested to be used in order to adapt the remote real environment to the master operator. The result of this transformation is called IFR.

Definition *An IFR is a transformation function which returns to the operator pertinenet informations about the teleoperation site in a modified presentation form while maintaining the task functionality parameters. This transformation depends on the application case and can be the identity (this is not what is needed however) when no change is made on the real environment during its feedback to the operator.*

Looking at a task to be performed by the performer in the remote environment, any complex task can be a succession of not complex elementary actions. The main purpose is neither the performer or the present remote working environment state. The purpose is a future environment state expressed throught its transformation. Thus only this transformation is interesting [7].

3.2 The hidden 'performer' concept

An IFR expressed by a whole virtual reality concept offer many advantages:

- The huge possible nature of, real environment → IFR, transformations with a large choice of functionality adaptations. Indeed VR techniques offer the possibility to build a world keeping an only functional copy of the real environment.

- It is easy to see that, in any IFR the first object to disappeared will be the 'picture' of the performer manipulating the real operational tool. This will allow to hide the complexity of the performer at the perceptual and the functional levels. This ligitimate the concept name which was applied first to teleoperation [7]. This 'repeal' of the performer is used to hide its complexity and require obviousely intermediary levels of automatic or semi-automatic interpretations.

- An IFR must be based on operator skill and the transformation concerns first this important aspect. For instance, assume that the teleworking system is composed by the surgeon (master) a robot (slave performer) and the surgical tool used to operate the patient. The surgeon knows to master the surgical tool, but is not familiar to master the robot used to manipulate the tool. In a classical teleoperation system, the master device is conceived to control the robot. Thus the surgeon will be asked to manipulate the tool through the robot. That makes, in all cases, the generation of suitable gestures not very natural. Using the hidden robot[5] concept the master tool can be designed to be a kind of a copy of the surgical tool enhanced with necessary actuation and design to allow haptic feedback, the patient may be represented using aumented reality while hidding from the picture the real robot and eventually the real tool.

- Possibility to integrate within the IFR additional tools to assist the operator and allow a kind of man-machine collaboration control, see figure 1.
- An IFR deals with time delay problem since there is no direct bilateral coupling between the master and the slave. This coupling was the main source of instability and transparency for teleoperation systems.

However, VR techniques may not totally garanty an ideal functionning of the teleworking system without a certain autonomy, to be determined, and requires preliminary calibration and error recovery procedures.

In figure 1, the hidden robot concept is illustrated through simulation. The task consisting in moving an object (Piece A). The IFR here consists in a whole virtual reality representation of the real world. The object within an IFR has been modeled as the real one. In general the aspect of the real object may change if necessary to adapt operator skill. Step 1 to 4 illustrate the interpretation layer which transforms natural operator hand actions into robotic commands. The cylinder arround the piece handle illustrates a virtual guide used to tacle with the poor d.o.f of the used robot. It allows automatic gripper positioning during the operator grasping phase. Of course neither the virtual or the real robot appears to the operator, only the pictures of the first line (those including the virtual hand) are seen.

4 Teleworking experiments

Many experiments has been conducted to validate the proposed scheme of 'hard' teleworking. These experiments are thouroughly quoted and discussed in [3][4][5].

[5] Since the performer is a robot

4.1 experimental set-up

As shown in figure 2, the teleworking experiments consists in a simple 4 puzzle pieces assembly within a fence on a table. The real remote assembly operation was to be performed by many slave robots; four in the first experiment and two in another. One slave robot was situated at the MEL[6], Japan, figure 3. All the robots had to perform the same task at different places (parallel teleoperation). Indeed it is easy to notice that these control experiment are very difficult to be achieved in parallel when using any traditional teleoperation architecture.

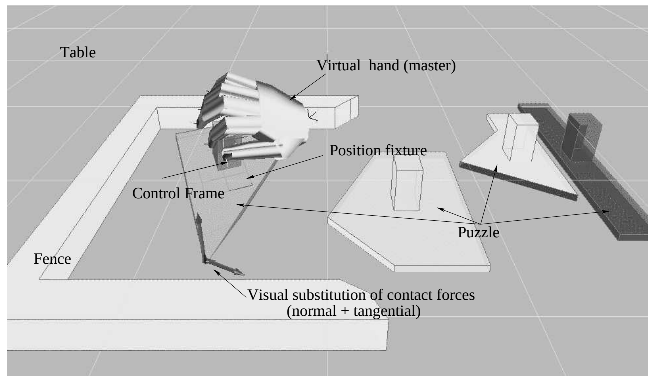

Figure 2: *A snapshot of the master IFR screen during teleworking.*

As shown in figure 3, the experimental set-up is composed by :

— the master station, an HP workstation used to render the IFR and, thanks to which, the operator performs the virtual task. Another HP workstation was used for the algorithms used for the transformation of operator actions into robots commands. A SGI workstation was dedicated, in a teleoperation stand-alone system, for video exchange which can help the operator in some situations (unrecovered errors, end of teleworking ...) to understand what is really happening in the remote site (safety level).

— I/O operator interface to act on the virtual hand (dataglove) and to change the point-of-view (joystick), etc.

The operator assembles the virtual puzzle using his own hands and skill. The visual and haptic feedback is local and concerns only the graphic representation of the remote task features without any remote robot, figure 2. The operator/IFR interaction parameters are sent to the second workstation in order to derive

[6] Mechanical Engineering Laboratory

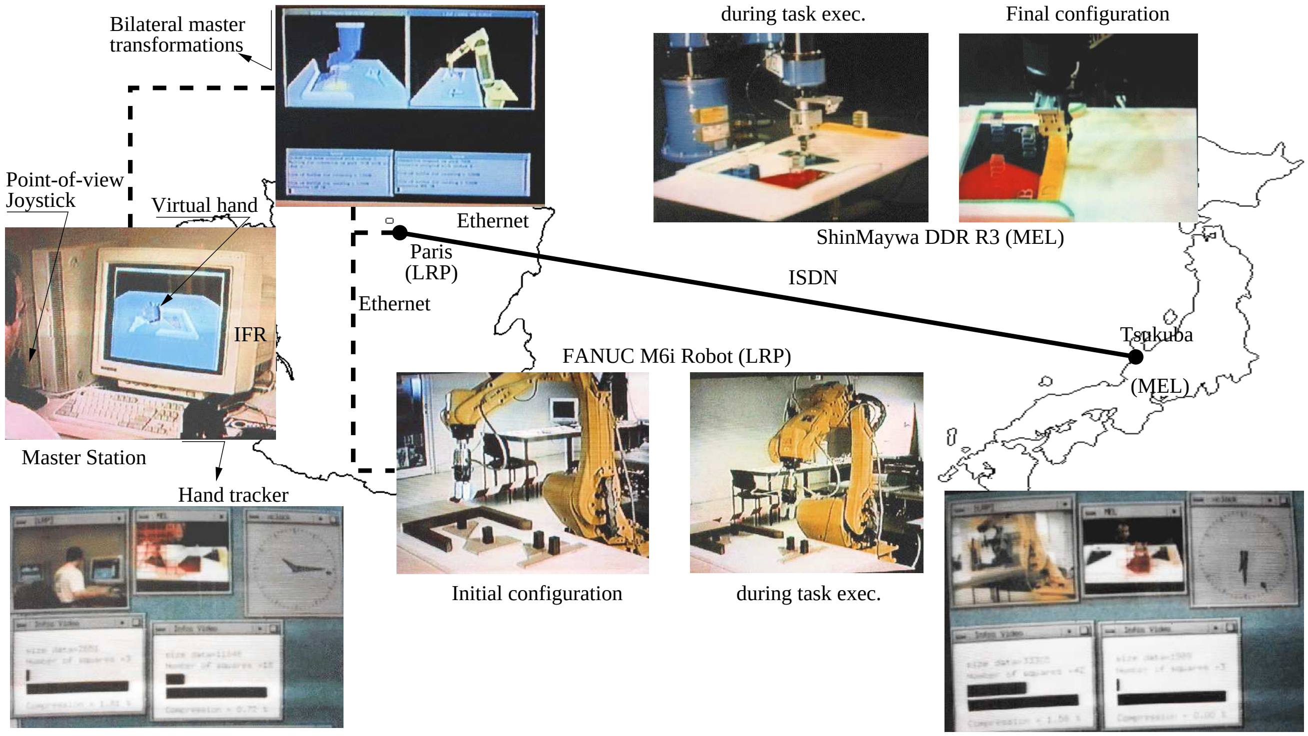

Figure 3: *Teleworking experiment— Parallel 4 puzzle pieces assembly using two distant slave robot and the hidden robot concept.*

robot actions. A graphic visualization of the transformations are rendered thanks to the implemented robot models (figure 3). This rendering is used for development purposes (algorithms check and results visualization) and is not involved by operator perception and feedback. If the performed operator actions are feasible in terms of robot or machine actions, they are sent to the remote real site. Obviousely, the set of the transformed sequential operator sample actions are the real task achievement. The remote site includes a *supervisor* software for error detection and automatic recovery from the IFR/real environment discrepancies. Its role and its conception are thouroughly discussed in [2].

4.2 Brief performance analysis

The performed experiments shows the feasibility of the proposed concept. However we remind that the main purpose of the proposed scheme is to adapt the control/feedback interface to the naturalness of operator working style and to allow operator skill transfert. A set of simple perfomance analyses was performed to have an idea about how far we are from the set goals. The performance indix has been chosen to be a ratio Γ_i between two times. The fist time, $T_{i,rw}$, concerns task (i) achievement by the remote machine (teleworking mode). The second time, $T_{i,lw}$, concerns the local realization of the similar task (i) using direct operator hand (not in a teleworking mode), then:

$$\Gamma_i = \frac{T_{i,rw}}{T_{i,lw}}$$

Let $\mathcal{T}$ be a set of tele-tasks used to perform the above criteria and, $\mathcal{N}_\mathcal{T} = \text{card}(\mathcal{T})$. The global performance indix is performed as:

$$\Gamma = \frac{\sum_i (w_i \cdot \Gamma_i)}{\mathcal{N}_\mathcal{T}} \quad \text{with} \quad \sum_i w_i = \mathcal{N}_\mathcal{T}$$

We are aware that this performance criteria is only qualitative. Indeed, taking into account time, does not take into account other interesting criteria such as tasks which could not be realizable by the operator. Thus we agree that Γ is not legitime in many cases. From table 2, the performed teleworking experiment showed that a big distance remains to reach the ideal 100 % rate. The performance are partly due to the (i) imposed synchronisation in the communication media to avoid loss of data (ii) robot speed limitations for safety purposes, etc.

	Local Mono-robot	Long distance Multi-robot
Γ_{puz}	$\simeq 5.55$ %	$\simeq 3.33$ %

Table 2: Best teleworking measured performances.

However, a local IFR/operator performance (without any teleworking achievement, i.e. pure virtual puzzle assembly task) was $\Gamma^{ev}_{puz} \simeq 16.6$ %. Indeed the limitations shows that eventual improvements concern obviousely the operator/IFR interaction first. They might be resumed as follow:

– stereoscopic visual feedback,

– more transparent haptic feedback and a realistic dynamic behavior implementation within the IFR. The lack of those items was noticed since the operator looses most of time during grasping and assembly phases.

5 Conclusion

In this paper a teleworking architecture has been outlined. It is suggested to fit teleoperation and virtual reality to conceive teleworking systems which allows physical modifications of remote working places.

As depicted in Section 2, many adaptations such as user-friendly master devices, the adaptation of the system to the operator skill, hidding the complexity of the remote performer... have been considered by a novel teleoperation architecture called: the hidden robot (performer) concept. This concept lies on the possibility to offer to the operator a functional copy of the real environment using virtual reality techniques which constitute an Intermediary Functional Representation (IFR).

The choice of an IFR imlpy obviousely an automatic error detections and recovery issued from IFR / real environment discrepancies. Thus, when unrecovered situations occur, it is usefull to forcast a possible intervention at the real representation level. Thus, it makes imperative to have a good understanding of the real scene and not only of it's representation in the virtual world. That means the 'hidden performer' cannot be permanently hidden.

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