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draft

Cet état de l'art n'a finalement pas été inclu dans le deliverable D3.1

1. From telemanipulation to teleoperation

1.1. The telemanipulation situation

The ground concept of telemanipulation somehow appeared in the ancient ages of humanity with the use of objects from environment as tools. With the help of such tools, humans were able to interact with their environment through another object (i.e. the tool). Therefore, the manipulated object was not to be maintained in hands, but could as well be located at some (rather short) distance of the human. Hence, the object was manipulated at distance with the help of another object, that is, it was telemanipulated.

In the telemanipulation process, the aim of the intermediary object between the human manipulating and the manipulated object is to mechanically couple the human hand and the manipulated object in order (1) to transmit the human's movements and forces to the object, according to some kinematical transformation, and (2) to transmit the objects rigidity and responsiveness to motion (i.e. inertia at first) to the human. The most representative for the telemanipulation task might be the pair of pliers: it lets the human manipulating an object at (short) distance, but allows for feeling the internal rigidity of the object.

1.2. The Link Trainer: a first design example of an electropneumatic telemanipulator

Even before the arrival of the first teleoperation systems, some kind of telemanipulation systems were developed for special purposes. One of the most famous is the Link Trainer [ASME, 2000]: Ed Link, working in the 1920s in the piano and organ factory of his father, had the idea to use the pneumatic systems used for organ construction for the design of a ground-based flight simulator. The trainer could sit in a scaled-down fuselage, which included the usual instruments and control devices (control column and wheel, pedals) usually found in planes of that time. The whole platform was moved by pneumatic systems, depending on the movements performed on the control instruments. Because of the particular motion coupling between the trainer gestures and the resulting motions of the Link Trainer, we can say, despite of the fact here that the manipulated object is the same than the manipulator, that this first flight simulator can be considered as a telemanipulator.

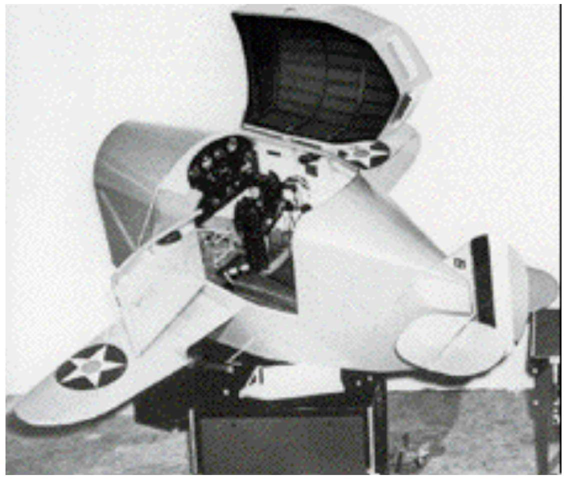

Figure 1 – A Link Trainer Model of the 40s

1.3. The first large developments of mechanical telemanipulators for nuclear purpose

In the first half of the century, with the growing of the first nuclear power plants in the United States, the need for further remote manipulation was urgent, since the radioactive materials manipulated were more and more harmful. Raymond Goertz and his colleagues designed the first mechanical telemanipulator for nuclear purpose at the Argonne National Laboratory in 1948 [Vertut and Coiffet, 1984]. If this is generally regarded as a major milestone in force feedback technology, the design was based entirely on mechanical coupling between the master and slave arms, using steel cables and pulleys. With its help, the operator was able to manipulate radioactive elements behind a heavy shield at a distance of several meters, and we can somehow consider this telemanipulation system as an extension in space of the first principle of the blacksmith's pair of pliers (even if it included of course a greater number of degrees-of-freedom). Starting from this first prototype, the Argonne Lab developed numbers of manipulators, derived from the same principle: a complex amount of linkage through which user's movements could be transmitted to the manipulated object and vice versa.

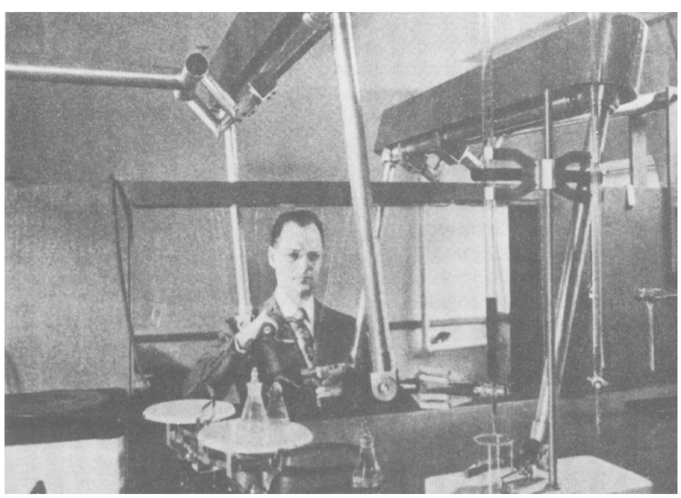

Figure 2 – Raymong Goertz using one of the first telemanipulators at Argonne Laboratories

It is a fact that in the late 40s, the field of electronics has reached some kind of first technological phase of maturity; the main components available are (1) the relay, which is a kind of reliable mechanical switch, but which contact speed is only of one thousands of a second to reach the open or close state; and (2) the vacuum tub, which is an electronic switch, its switching time being much more shorter, but its limitations still being considerable standby power and limited lifetime. Marvin Kelly had stated a few years before that these components, yet allowing for all things possible in telephony, would lead to limited progress in the future [Ross, 1998]. In 1945, Kelly establishes a research group at MIT Bell Lab to focus on the understanding of semiconductors.

In late 1947, Brattain and Bardeen, from the MIT Lab, demonstrate the action of the transistor for the Top Management of the Bell Laboratories, and in January 1948, the public announcement of the transistor discovery is being made [Brinkman et al., 1997]. Despite this announcement has no major impact in the press (only a few lines in the New York Times in July 1948), this first announcement will be someway quickly followed by increased boiling activities in the semiconductor domain.

Despite transistors are not still available for standard commercialization, the computer science has reached in the first 50s a first technological level, which allows for the development of the first calculators (the IBM 603 calculator in 1945, the ENIAC in 1946) and premises for the first electronic applications.

1.4. First teleoperation systems

In 1954, Raymond Goertz and his team develop another system, namely the E1 model, which morphology is quite similar to the previous telemanipulators, but in which the mechanical linkage between the master and the slave parts is replaced by a newer electrical servomechanism [Goertz and Thompson, 1954]. This first electrically controlled telemanipulator allows for seven suitable independent degrees-of-freedom. Each master and slave parts of the manipulator are equipped with electric motors, which are passively linked one to each other; their control signal being transmitted according to an amplified error position signal. Despite the fact that the damping forces still remain important and that the inertia effects are not negligible, the E1 arm is said to be performing extremely well and allowing for precise manipulation.

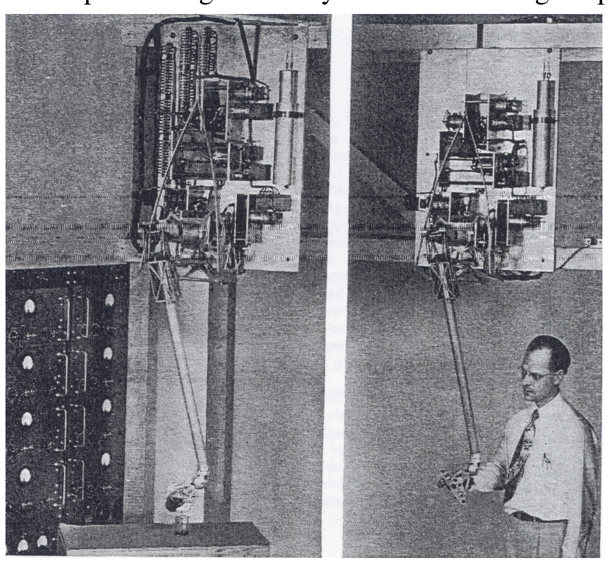

Figure 3 – Raymond Goertz and the E1 model, 1954

The E1 arm, which was the first arm to provide the mechanical linkage between the master and the slave parts by electrical means, is still considered today as one of the major cornerstones in the teleoperation field; with the use of a completely mechanical telemanipulator, the distance between the operator and the manipulated object could indeed not be extended at will because of the inertia of the mechanical linkage, and the friction forces due to the use of long linkage pieces, etc. But with the help of the electrical support for the transmission of movement's information, the remaining distance between the operator and the manipulated object wasn't anymore a problem. It was possible therefore to manipulate a remote object that could be located ten meters further, or in the next piece. In 1965, the E4 model developed at Argonne Lab was used with a television controller in order to allow such a use.

Even if the consciousness that a real change had appeared in the telemanipulation process came up to minds more than twenty years later, this first new system introduced by Goertz set up the begin of teleoperation. This process is defined by Vertut and Coiffet [Vertut and Coiffet, 1984] as a generalization of the concept of telemanipulation in space, not because of the spatial range, but because of the mobility and the loss of mechanical linkage, which obliges to introduce the tele-command or the servo-control.

From the first teleoperation systems to now, the use of the electrical signal to transmit information thanks to the first electronic systems in the early 50s to the large development of computer in the 80s allowed to introduce a new piece in the teleoperation chain. For instance, it was possible to introduce kinematical transformations in the teleoperation tasks [Kheddar, 2002]. This allowed the slave and master arms to have different morphologies and kinematical configurations. Because of the kinematical constraints, which were so much difficult to solve without the use of computer, the slave and master arms had to have the same kinematical configuration. Starting from the apparition of computer in teleoperation, it indeed leaded to the development of master arms for generic uses, and allowed for novel kinematical possibilities in the teleoperation chain.

1.5. Universal master arms and the decoupling between slave and the master sides

In 1980, Bejczy and Salisbury presented a first force-reflecting arm for telemanipulation. In their paper presentation, they pointed out the fact that the kinematical identity between the master and the slave parts was "a limiting factor for broadening the application of force-reflecting master-slave manipulator control technology" [Bejczy and Salisbury, 1980]. This arm, stated as a generalized (or universal) master arm, provided force feedback for its 6 degrees-of-freedom with generated forces up to 9,8N and torques up to 0,5N.m.

Starting from this period, in the late 70s and the first 80s, thanks to the great improvements in computational power, a real decoupling was possible in the teleoperation chain, in minds as well as in historical facts. It had became possible (1) to allow different kinematical configurations between master and slave parts, thanks to a better efficiency of the computer in calculations for cinematic transformations; (2) to completely synthesize the manipulated object. If for some applications, the close relationship between master and slave parts, as in teleoperation, was still needed and induced a close development of each part together, this allowed for a shift into two different domains. At one side, the development of gestural interfaces between human and computer became a whole technological field, with its own requirements; this would later be designed as the field of haptics. On the other side, the development of remote systems, such as slave arms, was more or less related to robotics, and telerobotics.

2. The arrival of the computer and the first gestural interfaces

On the one hand, the teleoperation field existed before the arrival of the computer, and the arrival of the computer in this field helped improving the quality of teleoperation tasks and brought new solutions for the resolution of major bottlenecks, such as kinematics control.

On the other hand, independently of the improvement of previously existing fields, the computer introduced major changes in the relation between humans and technology, and brought new uses as well.

2.1. Visionary visions of Engelbart and Sutherland

At the time when Sutherland published his visionary article about the *ultimate display*, the computer was already though as a tool for extending the human capabilities. The well-known vision of Douglas Engelbart in the 50s was to make of the computer a tool for enhancing human intelligence [Rheingold, 1991]. In 1962, Sutherland had been showing SketchPad, which was presented as a tool for enhancing the human intelligence as well, in the way that it allowed for the graphical representation of computerized information. It was actually the first time that a human-computer interface was presented, which was allowing for something else than the on/off selection of keyboard character keys. Later in 1970, Douglas

Englebart would present the ancestor of the mouse: a "X-Y position indicator for a display system" [Engelbart, 1970].

Further beyond, Sutherland presented in 1965 his visionary project of a computer capable of displaying –not only visually, but auditorilly and gesturally as well– "mathematical wonderlands constructed in computer memory", that is, *virtual worlds*. Coupled with the fact that it was now possible to manipulate an object at remote distance thanks to the first systems for teleoperation developed by Goertz and his team since the beginning of the 50s, it gave the idea two years later to Frederick Brooks, in 1967, to set up the GROPE project at University of North Carolina; the first idea was to make possible to see and manipulate a virtual model of a molecule and to feel (with the help of a gestural device) the resulting docking forces, that is, to manipulate an object entirely generated by the computer, with no physical reality. The first realization of this project was presented in 1971 at the IFIP conference [Batter and Brooks, 1971]: for the first time, it was possible to see and fell and force field entirely calculated by a computer. Relying on the conception of the computer of Engelbart and Sutherland as a tool to enhance human intelligence, Brooks showed that the tested students got a better understanding of the force fields presented thanks to the force feedback.

2.2. The first "Haptic" systems: towards Virtual Realities

The first idea of Sutherland had been fertilizing in the heads of researchers and scientists from the computer field in the first 70s. It was appearing, thanks to improvements in computer technology, that it became possible to completely represent an object in computer that we could see, hear and feel. Aside from the teleoperation field, which was more related to the manipulation on a remote object, this field of research was looking forward the multisensory representation of (non-real) objects located *inside* the computer. This particular field would be later called "Virtual Realities" by Jaron Lanier [Lanier, 1988].

At the United State, William D. Atkinson first describes in 1976 several "touch communication systems" [Atkinson & al., 1976] for human-computer applications. This paper contains the main key-ideas that will be later implemented: impedance-based systems such as the "Touchy Feely" or the "Touchy Twisty", haptic gloves (the "MagicGlove") and even force-reflecting devices making use of gas jets.

3. The computer and the instrumental relationship

In France, the first design of an interface for gestural communication between a human and computer is presented by Florens in 1978 [Florens, 1978] in his PhD thesis. The system is presented as a gestural transducer, allowing for force feedback along one degree-of-freedom. The system << **… JLF= description du système??. >>** The simulation of virtual objects is performed by electronic hardware, since the analogical treatment of the gesture (force and position) signals is still difficult to perform with computer treatment.

In 1981, a second version ("La Touche") is designed this time using the computer. << **Mettre la description ici >>**

Mettre une photo, 1981

4. Current general tendencies of Haptics

Nowadays, the development of haptic interfaces has reached a new stage; if the usability and the necessity of such devices may still be questioned, it is a fact that more and more devices are developed for more and more applications (especially in the teleoperation field, for instance for surgical applications). Important laboratories, such as the University of Pisa are especially involved in the development of new haptic devices, and important research projects are concerned as well by this field (the Network of Excellence

Touch Hapsys, dedicated as well to the development of new systems for haptics such as rheological devices). Commercial societies such as Sensable, Immersion, Haption have reached a first stage of maturity and tend to show that the field of haptics is still on the rise.

However, we may notice that if the low-level development of haptic is still available (for instance new design of cinematic structures or new systems for actuation), a new pole of activity is rapidly growing and taking more and more importance: *the development of integrated solutions for the design of haptic applications or uses*; that is, the development of new facilities around the existing haptic hardware currently available.

1. Development of embedded solutions for the integrated treatment of low-level signal processing tasks, such as kinematic transforms. See for example the Delta haptic device [Grange et al., 2001a, 2001b, 2001c] and the Delta TSC (appendix of the current document), where an electronic controller interfaces the haptic device to the host CPU: it performs the kinematic transforms (sends commands to the motor amplifiers, and transmits the device's position to the host PC) and is responsible for low-level safety tasks (monitoring of exceeding speeds, structure position limits and low-bandwidth calculations).
2. The integration of commercial or non-commercial haptic devices already available in other systems; for example, ReachIn Technologies [www.reaching.se] integrated the Phantom device in a desktop system in order to cope with the collocation problem: a semi-transparent mirror, coupled with a CRT raster display, displays the visual feedback at the location where the Phantom device is manipulated. Another specific field of application where various haptic systems are designed is the field of laparoscopic telesurgery; [Çavuolu et al., 1999] presented a laparoscopic workstation, where the master part of the system included the commercial Immersion Impulse Engine 3000 device (3 actuated degrees-of-freedom of 4), to which were added another 2 degrees-of-freedom device, in order to control the 6-dof slave part of the system
3. Software Development Kits and Application Programming Interfaces facilities are often provided with the purchase of commercial devices; these tools aim at facilitating the development of user-end applications, allowing the developer of the application not to have a specific knowledge of the low-level hardware and software requirements, and allowing for the development of applications at low cost and in a very reduced period of time.

5. References

[ASME, 2000] ASME (2000). The link flight trainer. Commemorative Brochures of the ASME Landmarks Program.

[Atkinson et al., 1976] Atkinson, W. D., Bond, K. E., Tribble, G. L., and Wilson, K. R. (1976). Computing with feeling. Computer and Graphics, 2:97–103.

[Batter and Brooks, 1971] Batter, J. J. and Brooks, F. P. (1971). GROPE-I: A computer display to the sense of feel. In IFIP congress 71, pages 188–192 (TA–4), Ljubljana, Slovenia.

[Brinkman et al., 1997] Brinkman, W. F., Haggan, D. E., and Troutman, W. W. (1997). A history of the invetion of the transistor and where it will lead us. *IEEE Journal of solid-State Circuits*, 32(12):1858–1865.

[Bejczy and Salisbury, 1980] Bejczy, A. and Salisbury, K. (1980). Kinematic coupling between operator and remote manipulator. Advances in Computer Technology, 1:197–211.

[Çavuolu et al., 1999] Çavuolu, M. C., Cohn, M., Tendick, F., and Sastry, S. S. (1999). A laparoscopic telesurgical workstation. IEEE Transactions on Robotics and Automation, 15(4):728–739.

[Engelbart, 1970] Engelbart, D. C. (1970). X-y position indicator for a display system. US patent 3,541,541, Palo Alto, California.

[Florens, 1978] Florens, J.-L. (1978). Coupleur Gestuel Retroactif pour la Commande et le controle de Sons Synthetisés en Temps Réel. Thèse de doctorat, Institut National Polytechnique de Grenoble, Grenoble, France.

[Goertz and Thompson, 1954] Goertz, R. C. and Thompson, W. M. (1954). Electronically controlled manipulator. Nucleonics, 12(11):46–47.

[Grange and Conti, 2001] Grange, S. and Conti, F. (2001). The delta haptic device as a nanomanipulator. In SPIE Microrobotics and Microassembly III, Boston MA.

[Grange et al., 2001a] Grange, S., Conti, F., Helmer, P., Rouiller, P., and Baur, C. (2001a). The delta haptic device. In Mecatronics 2001, Besançon, France.

[Grange et al., 2001b] Grange, S., Conti, F., Helmer, P., Rouiller, P., and Baur, C. (2001b). Overview of the delta haptic device. In Eurohaptics ’01, Birmingham, England.

[Kheddar et al., 2002] Kheddar, A., Coiffet, P., and al. (2002). Téléopération et réalité virtuelle. In Kheddar, A. and Coiffet, P., editors, Traité IC2. Systèmes Automatisés. Lavoisier Hermès.

[Lanier, 1988] Lanier, J. (1988). A vintage virtual reality review.

[Rheingold, 1991] Rheingold, H. (1991). Virtual Reality. Summit Books/Simon & Schuster, New York.

[Ross, 1998] Ross, I. M. (1998). The invention of the transistor. Proceedings of the IEEE, 86(1):7–28.

[Vertut andCoiffet, 1984] Vertut, J. and Coiffet, P. (1984). Les Robots, volume 3A: Teleoperation, Evolution des Technologies. Hermès Publishing, Paris, France.