Dans D3.1
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1. Cobots:

1.1. Definition of cobots:

Cobot stands for collaborative robot. This term has been proposed first time by Edward Colgate and Michael Peshkin [Colgate et al., 1996b]: cobots are mechanical interfaces designed to interact with people without masking the mechanical interaction between the human (manipulating-person) and the manipulated object. The philosophy of such systems remains indeed in a shared control of motion between the user and the cobot, and in the fact that a cobot mechanically interacts both with the human and the manipulated object.

In such systems, the source of mechanical energy remains the user, and a cobot is only able to modify the energetic link between the user and the manipulated object: from that point of view, the cobot is a passive device because it does not bring supplementary energy to the human or to the manipulated object. In other words, if the user does not move the manipulated object, the cobot is not able to generate motion on its own.

1.2. Cobots as nonholonomic systems:

Hence, cobots are particular nonholonomic systems, as they can modify the available taskspace of the manipulation[1] [Colgate et al., 1996a]. In nonholonomic systems, the number of degrees of freedom currently available (i.e. the dimensionality of the space of available velocities at any instant) might be inferior to the taskspace dimensionality, which refers to the space of endpoint poses that can be reached over time.

Two functional modes are commonly available in cobots. the first one is referred as the *free mode*, in which the number of available degree-of-freedom available corresponds to the dimensionality of the taskspace; in this mode, the possible reduction of the number of degree-of-freedom compared to free movement does not come from the interposition of the cobot between the human and the manipulated object, but from the interaction of the human with the object, and from the interaction of the object with its environment (for instance, I cannot move a book lower because it lays on the table). The second available mode in cobot control is *path mode* [Peshkin and Colgate, 1999]. By limiting the number of degree-of-freedom available in the interaction between the human and the manipulated object, a cobot can constraint the possible movements to a single path (i.e. reducing the number of degree-of-freedom to 1) or enclose the taskspace by *virtual surfaces* (1 or more degree-of-freedom).

1.3. The programmable constraint machine and CVT

The functional core of cobots remains in the CVT (Continuously Variable Transmission) concept [Gillespie et al., 2001]. This kinematical mechanism ensures that the whole cobot remains coupled to the ground (through the mechanical structure of the cobot, including CVT), but still allows modifying the way the end-effector movements are constrained. The simplest example illustrating this concept is the rolling wheel: the user can move a wheel rolling on a plane, which rotating angle is controlled by another system. By monitoring the

[1] A holonomic system constrains both position and velocity of two linked parameters. At the opposite, a nonholonomic system, constraining two parameters in position, does not constrain these parameters for velocity as well, and vice versa.

forces applied by the user on the wheel, it is possible to determine the rolling direction exerted by the user. By orientating the wheel, it is then possible to allow user's movements by orientating the wheel according to the forces applied, or on the contrary to xxx the movements by steering the wheel perpendicular to the direction of the force applied. (mettre une figure, de Colgate 1996) At last, if the steering angle is correlated to the applied force and the angular speed of the wheel, it is possible to constrain the user's movements to a predefined path on the plane.

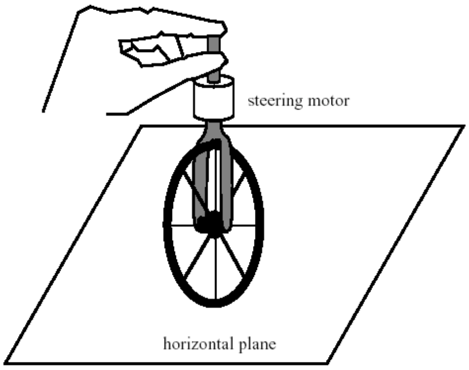

Figure 1-1 – An elementary example of CVT (from [Colgate, 1996])

Starting from the elementary CVT system of the steered wheel rolling on a plane, it is possible to extend the principle of constrained movement to a taskspace containing more than 2 dimensions [Gillespie et al., 2001]. [Peshkin et al., 2001] shows the simple example of the steering wheel, and its extension in the *Scooter prototype*, which is a three-wheeled cobot, able to implement unilateral virtual surfaces as well as free mode in its x-y-THETA taskspace. The added third wheel brings stability to the system, and allows for the reduction of kinematical singularity. This model has been implemented in General Motors cars factory [Peshkin et al., 2001], where the cobot helps the operator moving the door's car next to its body by supporting the door's weight, and constraining the door's movement to a predefined path, preventing the door marring the car's surface.

1.4. Applications for the use of cobots

Because the design of cobots is only based on CVT, a cobot system does not have actuators in direct mechanical interaction with the user. Cobots make use of actuators only to modify their kinematical configuration. (dans ce cas, est-ce qu'on peut quand même dire que ce sont des actuateurs?). The stiffness of a simulated virtual surface does indeed not depend on the stiffness provided by the actuators, but by the rigidity of the cobot's structure, and by the friction forces generated at the point of contact between the cobot and the ground. Thus, the main interest of cobots is that the can implement stiff surfaces without the need of costly actuators. Furthermore, this avoids the problem of stability, which engineers of haptic devices have to cope with.

One typical use of cobots might be the image-guided surgery, where the movements of the surgeon are assisted by a computer through a mechanical interface. In that kind if situation, the user still needs a great sensitivity of the manipulated object (which is allowed by the cobot since the user still remains mechanically 'in contact' with the manipulated object), but rather needs help for movements precision for instance. In such situations, the use of the cobot was said to be relevant.

1.5. Towards active cobots

The part of the environment to which the CVT was mechanically linked (for instance the ground in the case of the steered wheel) is usually inert in the first devices presented. [Peshkin et al., 2001] and [Faulring et al., 2004] present active cobots, where a central rotative shaft linked to every CVT brings to them motion, thus providing mechanical energy to the end-effector along each one of the degrees-of-freedom, depending on the angle position of each of the CVT.

1.6. Limitations of cobots: (à mettre ou pas? à développer?)

It seems to the authors of this State of the Art that the main drawbacks of cobots are the fact that they cannot implement soft contact or soft interaction.

1.7. References:

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