As noted hereinabove, an ideal speed reducer has 2 ports. In the ideal mechanical differential, one **302** of the 2 ports of the first speed reducer **301** is coupled to one **303** of the 2 ports of the second speed reducer **304**. In this manner, each of the 2 speed reducers **301** and **304** is left with a free port **305** and **306**, respectively. In addition to these two free ports **305** and **306**, a third free port **307** connected to the ports **302** and **303** enables an interaction with the two speed reducers **301** and **304**.

[**0073**] Referring to FIG. **3**, the ideal mechanical differential is characterized by the following set of equations:

$$\begin{cases} \dot{x}_1 + K \cdot \dot{x}_2 = (1 + K) \cdot \dot{x}_3 \\ F_2 = K \cdot F_1 \\ F_3 = (K + 1) \cdot F_1 \end{cases}$$

[**0074**] where subscript **1** refers to the third free port **307**, and subscripts **2** and **3** refers to respectively the two free ports **306** and **305**, respectively.

[**0075**] Real Source of Force/Torque

[**0076**] Ideal sources of force/torque are impossible to build in practice. However, direct drive actuators have characteristics close to those of ideal sources of force/torque because they have a very low mechanical impedance, i.e. low inertia, low friction, etc. As illustrated in FIG. **4**, a direct drive actuator can be represented by a source of force/torque **401** connected as illustrated in FIG. **4** with a viscous damper **402**, a mass **403** and a spring **404**. The force/torque output **405** is located across the spring **404**. The damping coefficient b of the viscous damper **402** and the value M of the mass **403** should be as small as possible and the stiffness value k of the spring **404** should be as high as possible.

[**0077**] A real source of force/torque can also be built, as illustrated in FIG. **5**, by combining a mechanical spring **502** having a low stiffness k connected with a real source of speed **501**. The force/torque output **503** is located across the spring **502**. An architecture as illustrated in FIG. **5** is known as <<Series Elastic Actuator>>. As well known to those of ordinary skill in the art, in this architecture, an adequate feedback force/torque controller (not shown; this type of controller is well known to those of ordinary skill in the art and for that reason will not be further described in the present specification) is required to build the real source of force/torque. The resulting bandwidth of the source of force/torque is determined by the spring stiffness k and by the bandwidth of the source of speed **501**.

[**0078**] Real Source of Speed

[**0079**] Ideal sources of speed are impossible to build in practice. However, hydraulic actuators, as shown on FIG. **6**, have characteristics close to ideal sources of speed because they have a very high mechanical impedance, i.e. high stiffness. As illustrated in FIG. **6**, the hydraulic actuator is represented by a source of speed **601** connected with a spring **602**. The source of speed output **603** is located across the spring **602**. The stiffness value k should be as high as possible.

[**0080**] A real source of speed can also be built by combining a very high ratio gearbox in series with a real source of force/torque, as illustrated in FIG. **7**. The real source of speed of FIG. **7** is represented by a real source of force/torque **701** as illustrated in FIG. **7** connected with a viscous damper **702**, a mass **703** and a spring **704**. The real source of force/torque of FIG. **7** also comprises a speed reducer **705** having a first port connected across the spring **704** and a second port **706** forming the speed output. In FIG. **7**, a small impedance of the real source of force **701** is multiplied by the square of the gearbox ratio K (ratio of the speed reducer **705**) providing high mechanical impedance in open loop. Moreover, as known to those of ordinary skill in the art, an open loop mechanical impedance can be increased with an appropriate feedback speed controller (not shown; this type of controller is well known to those of ordinary skill in the art and for that reason will not be further described in the present specification).

General Description of an Actuator According to Non-Restrictive Illustrative Embodiments of the Present Invention

[**0081**] The non-restrictive illustrative embodiments of the actuator according to the present invention provide compact implementation designs for high performance actuators. These actuators are particularly, but not exclusively, suitable for integration in robotic mechanisms and comprise a mechanical differential. Although differential coupling between an intrinsically high impedance transducer and an intrinsically low impedance transducer provides similar benefits as serial coupling of the transducers, differential coupling enables interesting design implementation possibilities, particularly, but not exclusively, for rotational actuators.

[**0082**] Differential Actuation

[**0083**] Referring now to FIG. **8**, an actuator according to an illustrative embodiment of the present invention comprises a mechanical differential **801** as described hereinabove with reference to FIG. **3**, to which two transducers T**1** and **72** are coupled so as to create a compact high performance actuator, suitable in particular but not exclusively for robotic interaction tasks.

[**0084**] More specifically, the mechanical differential **801** comprises a first mechanical speed reducer **804** of ratio 1:K+1 as illustrated in FIG. **2** with ports **805** and **806** and a second mechanical speed reducer **802** of ratio 1:K as illustrated in FIG. **2** with ports **807** and **808**. Transducer T**1** is connected to port **805** of the mechanical speed reducer **804** while a load **803** is connected to port **808** of the mechanical speed reducer **802**. Ports **806** and **807** are interconnected and both connected to transducer T**2**.

[**0085**] The principle of operation of a differential actuator according to an illustrative embodiment of the present invention is not scale dependant. For example, micro actuators using MEMS technology or macro actuators using standard components can be built still using the same principle of operation.

[**0086**] Physical implementation of the mechanical differential **801** of the actuator of FIG. **8** does not change the principle of operation of the differential actuation process. Possible implementations of the mechanical differential include the use of, amongst others, a standard gearbox, a harmonic drive, a cycloidal gearbox, a bar mechanism, a cable mechanism and any other types of mechanism that implement a differential function between 3 mechanical ports.