PowerGlove

Concepts and current results

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Dynamic interaction between the human body and the environment can be assessed by measuring force and estimating velocity at their interface. A sensorized glove with movement and force sensing is developed in which this principles is applied.

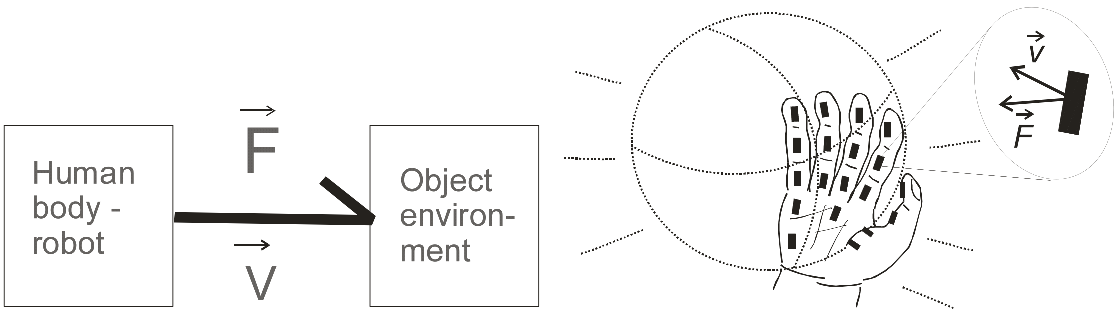
Keywords – inertial movement sensing, six degree-of-freedom force / moment sensing, power sensing, load identification, dynamic interaction.

1. INTRODUCTION

Measuring the physical interaction between the human body and the environment is important in medicine, ergonomics and sports. Potential applications include the assessment of motor performance in rehabilitation, measuring whether the human body is loaded within safe limits in ergonomics and training for optimal performance of motor activities in sports.

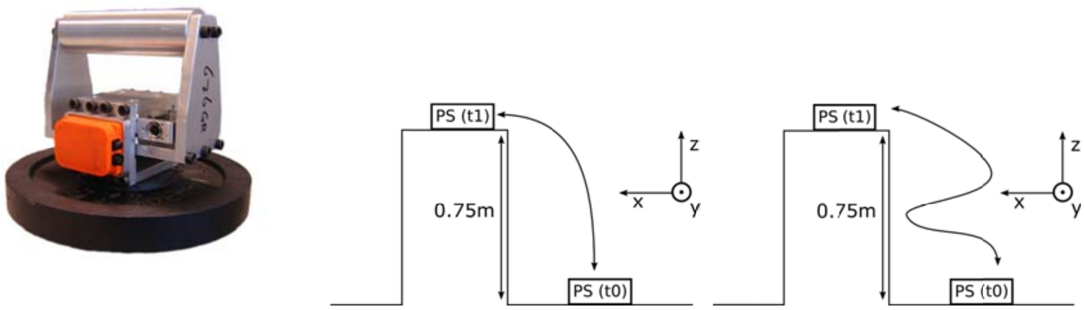
The physical interaction between the human body and the environment can be assessed by measuring force and velocity at their interface (Fig 1a). Power transfer can be derived from the inner product of force and velocity [1,2], the dynamics of environment can be derived by relating movement to force under conditions in which the human body is the actor and the environment behaves passively and does not change in certain time periods [1,3].

It is the objective of our current PowerSensor project to demonstrate these principles and to develop a sensorized glove that is able to measure hand and finger movements as well as interface forces. The sensor system that is to be applied on the finger tips and selected finger and hand segments will include inertial and magnetic sensors for movement and an accurate 3D force sensor for interface forces (Fig. 1b). Optionally, the 3D force sensor may be extended by 3D moment sensing. This paper provides an overview of our current research achievements in this area, with reference to papers that provide more detail.



(a) (b)

Figure 1. The PowerGlove concept [1]. (a) Dynamic interaction between the human body and the environment can be assessed by measuring force and estimating velocity at the interface, (b) a sensorized glove with movement and force sensing is developed in which these principles are applied.



(a) (b)

Figure 2. Feasibility demonstration of power sensing and load identification. A mass was moved from the ground to a table following arbitrary trajectories (b) using a sensorized handle with an Xsens inertial sensing unit and an ATI-mini45 6 DoF force/moment sensor (a). Work performed and mass were estimated from measured movement and force information and compared to changes of potential energy and actual value of the mass. Similar tests were performed using spring loads [2,3].

2. Materials and Methods

Feasibility demonstration of concepts

We propose two concepts concerning the assessment of the dynamic interaction between the human body and the environment, being the estimation of power transferred and dynamics of the environment.

<u>Concept 1: Sensing power transfer between the body and the environment</u>

The power transfer between the body and the environment was estimated for the displacement of an unknown load. First, relevant movement quantities were estimated: the sensor orientation was estimated at any moment by integrating the signals of the 3D angular velocity sensors and correcting the resulting estimate for drift, applying known orientations at the start and end of the movement. The 3D acceleration was transferred to global coordinates using the estimated orientation at any moment. Subsequently, the gravitational acceleration was subtracted and the resulting acceleration integrated to velocity, and velocity subsequently to change of position. Integration drift was reduced by applying known zero velocity at the start and end of the movement, information about change of height was not used. Power transfer was estimated at each moment in time by multiplying force and velocity, multiplying moment and angular velocity and adding both components of power transfer. Performed work was estimated by integrating power transfer over time [2].

<u>Concept 2: Identifying load dynamics</u>

A second order load model, including mass, damping and stiffness parameters, was identified by relating estimated acceleration, velocity and displacement to measured force as function of time using least squares estimation [3]. These movement quantities were derived as described above.

<u>Experimental methods applied in the feasibility demonstration</u>

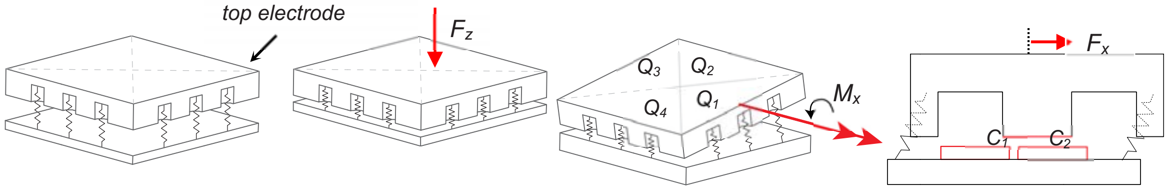
Work performed and load dynamics were estimated from inertial movement sensing and force/moment sensing at the interface between a handle and the load, while displacing the load. The estimated work performed was compared to the change of potential energy and the load dynamics with the known characteristics of the load (Fig. 2).

Development of the PowerGlove

In addition to demonstrating the principles of dynamic interaction assessment, we are developing a prototype of the sensorized glove, including movement and force sensing.

<u>Inertial sensing of hand and finger movements</u>

Hand and finger movements are estimated by fusing inertial and magnetic movement sensing on the segments of the fingers and the back of the hand with a kinematic anatomical model of the hand. The applied optimal estimation method was initially developed using a model that generates sensor signals when performing certain hand and finger movements. It is now evaluated using a complete inertial/magnetic sensor module on the back of the hand and 3D accelerometers and magnetometers on the segments of index finger and thumb [4]. A more extensive distributed movement sensing system, including 3D gyroscopes is currently being developed.



(a) (b) (c) (d)

Figure 3. Working principle of the six degree-of-freedom force/moment sensor [5] (a,b) normal force sensing, (c) moment sensing, (d) shear force sensing

<u>Six degree-of-freedom fingertip force/moment sensor</u>

The six degree-of-freedom fingertip force/moment sensor consists of a silicon top electrode which is supported by many thin silicon pillars. These pillars are the spring elements of the force sensor for all degrees of freedom. An applied load to the sensor results in a small displacement of the top electrode relative to the bottom part. Capacitive read-out is used to detect this displacement, determining all axial force components and all torque components simultaneously. For determining forces/moments which cause out of plane displacement of the top part, four triangular electrodes are realized in the bottom wafer (Fig. 3a,b,c). Each force component is determined by measuring the change in capacitance between these electrodes and the top wafer. For measuring shear forces and a moment around the normal axes, comb-shaped electrodes are realized in the top and bottom part. An applied shear force causes a differential change in capacitance with respect to the top wafer (Fig. 3d) [5].

3. Results

Feasibility demonstration of concepts

The estimated work performed on a 9.4 kg mass and a spring with a spring constant of 88 N/m appeared to be accurate within 4 % for varying movements with durations between 3 and 5 s [2].

The mass parameter of the mass load was identified within 5 % error, with negligible forces due to stiffness and damping. The stiffness parameter of the spring load was identified within 3 % error with negligible forces due to mass and damping. Variances accounted for were above 99 %.

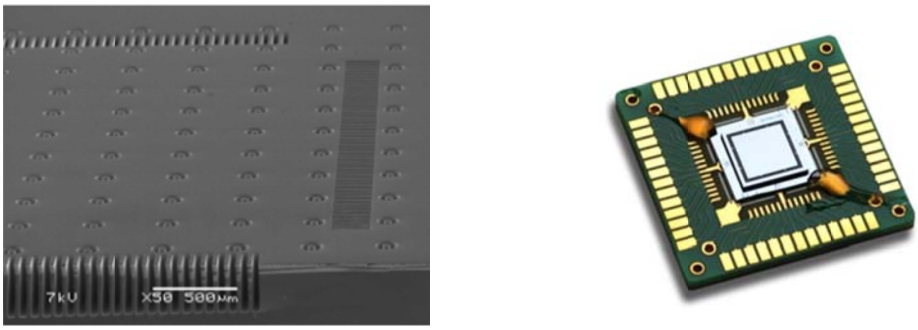
Development of the PowerGlove

<u>Inertial sensing of hand and finger movements</u>

The first version of the inertial and magnetic movement sensing system, including a complete Xsens movement sensing module on the back of the hand and small distributed PCBs with 3D accelerometers and magnetometers on the segments of the index finger and the thumb, is illustrated in figure 4. Further descriptions of the sensor fusion algorithms, this movement sensing system and the initial evaluation of measuring hand and finger movements are provided in another paper in this proceedings [4].

(a) (b)

Figure 4. (a) first version of a movement sensor PCB with 3D accelerometer and magnetometer, (b) the first prototype kinematic glove with partial instrumentation of index finger and thumb [4]



(a) (b)

Figure 5. (a) SEM picture showing the top electrode with the silicon pillars and the comb-structure for measuring forces and moments, (b) Six degrees of freedom force-moment sensor mounted on a test PCB [5]

<u>Six degree-of-freedom fingertip force/moment sensor</u>

The six degree-of-freedom force-moment sensor has been realized and tested [5] (Fig. 5). The force range is up to 50 N in normal direction and 10 N in shear direction, the moment range is between 0 and 25 N·mm around each axis. Force measurements showed a full scale error of 0.9 % in normal and of 0.4% in shear directions, moments showed a full scale error of 2.8% around the normal and 1.1 % around the other axes.

4. DISCUSSION

It should be noted that load identification was performed under the condition that the human body is actively perturbing a constant passive load. When the load is varying and/or generates forces on the human body, the estimated dynamics are the combined effective dynamics of both human body and load, since measurements are performed in a closed dynamic loop. It is, therefore, important to assess the measurement condition in daily-life situations, possibly by identifying the performed activity. This is to be further investigated.

In the coming period, we plan to combine inertial and force sensors in the prototype sensorized glove and demonstrate the power sensing and load identification principles when interacting with the environment using the glove.

In addition to assessing the dynamic interaction between the human body and the environment, the sensorized glove is expected to be useful in biomechanical analysis of hand function and assessment of human motor control, as well as in animation and serious gaming.

5. ACKNOWLEDGMENT

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