A tactile handle for cane use monitoring

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Abstract— **Assistive ambulatory devices are used for gait rehabilitation and assistance. In both cases, their benefit is greater when they are used properly. As for canes, embedded sensors can be used for monitoring purposes. In this paper, a custom tactile handle equipping a cane is described. It is composed of cost-effective commercially available pressure sensors. Experimental results involving 10 subjects show that the developed handle can provide information on the cane orientation as well as on the load applied to it during assisted gait. These data can help monitoring the cane usage and misuses detection.**

I. INTRODUCTION

Canes are often prescribed to avoid falls in the elderly [1]. They are also used in post-stroke patients in order to allow a safer gait and rehabilitation [2], [3]. In both cases a monitoring of the cane usage is necessary. In the elderly, the monitoring is intended to avoid misuses that can lead to accidents [4]. For post-stroke people, the supervision of the cane data can provide insight into the recovery progress and help improving the physical therapy [3].

Research work has been therefore dedicated to the development of instrumented canes. In [7], a force sensor was simply attached to a cane shaft in order to measure interaction forces. The device was used along with a treadmill and a virtual reality setup for rehabilitation purposes. In order to extend monitoring to daily living activities, instrumentations based on embedded sensors and processing units have been proposed. In [5], a cane has been equipped with a three-axis accelerometer, a three axis gyroscope and two pressure sensors. The accelerometers and gyroscopes are used to measure the cane orientations and its linear accelarations. One pressure sensor mounted on the cane distal tip acquires the load force, while the second, attached to the handle monitors gripping force. An embedded MircoLeap processing unit gathers data from the sensors. Audio alarm are emitted to provide feedback to the user. In [6], the applied force and the cane angle are also monitored. To this aim, a load cell and and a three-axis accelerometer are used. These data are acquired by a micro-controller that provides also an audio feedback to inform users on how they are using the cane for bearing their weights.

In this paper, a tactile handle monitoring both the load force applied to the cane and the orientation angle of its shaft in the sagittal is proposed. The tactile handle is composed by cost-effective pressure sensors. Its conditioning electronics are embedded on a small electronic board. This tactile handle has been used to equip a conventional cane. A six-degree-of-freedom force sensor and an inertial measurement unit are also equipping the cane to obtain ground truth measurements. Ten healthy subjects, whose gait has been artificially altered, carried out a five meter an a half walk using the cane. Strong correlations have been found between data obtained from the tactile handle and the load applied to the cane as well as its shaft orientation .

The sequel of the paper is organised as follows. In section II, the hardware used during the experiments is described. The tactile handle design is emphasized. Moreover, the experimental protocol as well as data processing are detailed. Section III is dedicated to the description and the discussion of the results. In section IV, conclusions and a description of future investigations are given.

II. MATERIALS AND METHODS

In this section a description of the instrumented cane is first given. The tactile handle is then described with more detail. Afterwards, the subjects' equipment and the experimental protocol are described. Finally, the data processing is explained. The relevant parameters extracted from the handle tactile sensors are described. The methods used to find correlations with the force applied to the cane as well the orientation of its shaft are given.

A. Materials

The whole instrumentation is first described. The tactile handle is then detailed.

1) Instrumented cane: The experimental setup is shown in Fig. 1. The instrumented cane is composed of the custom tactile handle and a shaft of a classical cane, which height can be adjusted to fit each user. This shaft encloses an ATI Mini45 six axis force sensor. An inertial measurement unit (IMU) is also attached to the cane shaft. The force sensor measures the load applied to the cane, while the IMU captures its orientation thanks to the RAHS algorithm running on it. The force sensor z axis corresponds to the cane shaft and allows measuring the load force. The IMU is used to measure the cane pitch angle i.e the orientation

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of the cane with respect to the vertical in the sagittal plane. One can notice that described instrumentation does not modify drastically the inertial and mass parameters of the cane.

The handle sensors data are acquired using a custom board attached to the cane. An embedded Arduino Due micro-controller acquires the orientation angles computed by the IMU. The Arduino Due and the handle board communicate the acquired information to a personnel computer through an USB connection. The force sensor is connected to its amplifier, which output is read by a National Instruments NI-USB-6211 acquisition card. This card is also connected to the personal computer to provide force data. All the data are synchronously acquired at a rate of 40Hz.

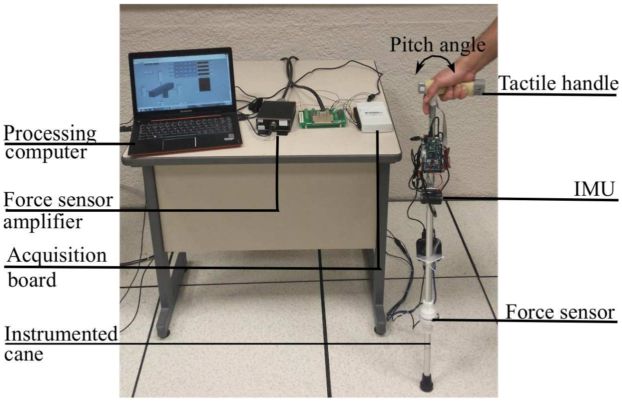

Fig. 1. A view of the experimental setup

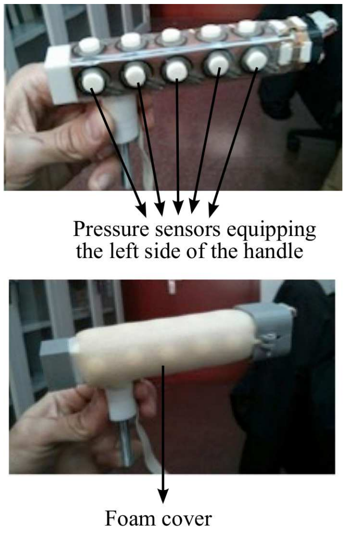

Fig. 2. A close view of the handle

2) Tactile handle: The tactile handle is a parallelepiped which dimensions are 23 mm×23 mm×151 mm (Fig. 2). Each of the four faces of the parallelepiped intended to be in contact with the hand is equipped by a printed circuit board (PCB). Five force sensing resistor (FSR) sensors, which measure pressure, are mounted on each PCB, except on the lower side. On this side, there are only three FSR sensors. Indeed, this side is used to attach the cane shaft and subsequently, less space is available for the sensors. The PCBs are connected forming an array of four rows by five columns of sensors. Note that there are only eighteen sensors. The sensors used are the FSR402 from Interlink Electronics. Round pads have been placed on their tops to concentrate the pressure on the active area, thus enhancing the measurements. Finally, the whole handle is covered by a foam to make the cane handling more comfortable. The array of sensors is wired to a conditioning electronics board. This board is based on a Microchip PIC18F4680 micro-controller. It includes transimpedance amplifiers and analog to digital converters. This way, when scanning the array, each sensor pressure is received as a digital value by the micro-controller. The digital value depicts the output voltage of the applied pressure.

B. Methods

The experimental protocol is first described before detailing the data processing.

1) Protocol: Ten healthy volunteers with an average age of 25.3 years old (min:21, max:32) have been selected to participate to the experiments. They were equipped with a knee brace and a modified sole in order to simulate walking problems. All subjects gave written informed consent. The experiments meet the ethical principles of the declaration of Helsinki. Subjects have been asked to walk for a distance of 5.5m using the cane, at their preferred speed. Each subject underwent four trials. During the experiment, the pitch angle, the force sensor measurements and the tactile array data from the handle have been captured as detailed in the previous section. The subjects were naive about the purpose of the experiments.

2) Data analysis: In this study, the objective is to find out correlations between the tactile handle outputs and respectively the load applied to the cane and its shaft orientation. Therefore, the two pairs of data have been examined:

- *The handle upper side center of pressure - The cane pitch angle:*
  Here, the aim is to study, the correlation between the pitch angle of the cane and the outputs of the tactile handle. The pitch angle is the angle defined by the cane and the vertical in the sagittal plane. We hypothesize that this angle is correlated with the center of mass of the pressure sensors equipping the handle upper side, which will be called Center of Pressure and denoted CoP_u. The latter is computed as follows:

  $$CoP_u = \frac{\sum_{i=1}^{5} x_u(i) p_u(i)}{\sum_{i=1}^{5} p_u(i)} \tag{1}$$

  where $x_u(i)$ and $p_u(i)$ are respectively the position and the pressure value of the i^{th} sensor of the handle upper side. At rest, CoP_u is the center of the pressure sensor which is next to the shaft.

- *The handle upper side mean pressure - The force applied along the cane axis:*
  Here, the objective is to study the correlation between the force applied to the cane axis and the upper side mean pressure. This mean pressure is defined as follows:

$$Mean_u = \frac{\sum_{i=1}^{5} p_u(i)}{5} \tag{2}$$

For each trial, the data corresponding to the first and the last walking steps are removed. They are considered as transients and not representative of steady gait. The noise of the force sensor data is removed using zero phase low-pass filtering (a forward reverse processing is implemented).
Each subject mean behavior is then computed. As the subject velocity across the trials may vary slightly, the completion of the task do not take necessarily the same amount of time. The mean duration of the four trials is taken as a basis. The CoP_u, $Mean_u$, load force and pitch angle variables are then interpolated or extrapolated to fit the chosen duration. A mean CoP_u, $Mean_u$, load force and pitch angle trajectories are finally computed .
To assess the associations between on the one hand the CoP_u and the load force and on the other hand the $Mean_u$ and the cane pitch angle, Pearson and Spearman correlation coefficients [8] are computed for each subject using the mean trajectories.

III. RESULTS

The computed correlation coefficients between the cane pitch angle and CoP_u and between the load force and $Mean_u$ are provided in table I. All the reported coefficients are statistically significant. Generally a strong association between two data sets leads to a correlation coefficient of 1 or -1. Pearson's method gives good results if the association is linear while Spearman's is less restrictive. A good correlation is found provided that a monotonic association exists between the data sets.
The reported data in table I show that the two coefficients are similar and generally close to 1. This indicates that a strong linear correlation exists between the data sets.
To illustrate the reported results, one trial of subject 8 (which is representative of the group) is taken as an example. In Fig. 3, a linear regression between the cane pitch angle and CoP_u is given. In Fig. 4, the same analysis is done to illustrate the relationship between the load force and $Mean_u$. In the two figures, the identified linear equation is given. These equations are then used to compute estimations of the pitch angle and the load force based respectively on CoP_u and $Mean_u$. The results are depicted in figures 5 and 6.
These results show a good association between CoP_u, $Mean_u$ and respectively the cane pitch angle and the load force. The observations are in line with the intuition. Indeed the only way to cancel the variations of CoP_u, while rotating the cane around its tip, is to move the whole arm in order to keep the hand inner surface parallel to the handle. This moment is not natural. Moving naturally and comfortably imply a change of CoP_u. The correlation between $Mean_u$ and the load force is intuitive since force and pressure are two related physical variables.

TABLE I
CORRELATION COEFFICIENTS

Suject		**Correlation (r)**	
		Pitch/CoP_u	Load Force/Upper pressure
1	Pearson	*0,78*	*-0.94*
	Spearman	*0,78*	*-0.89*
2	Pearson	*0,87*	*-0.94*
	Spearman	*0,89*	*-0.89*
3	Pearson	*0,72*	*-0,95*
	Spearman	0,69	-0,93
4	Pearson	*0,93*	*-0,92*
	Spearman	*0,93*	*-0,89*
5	Pearson	*0,80*	*-0,89*
	Spearman	*0,80*	*-0,88*
6	Pearson	*0,91*	*-0,93*
	Spearman	*0,90*	*-0,89*
7	Pearson	*0,93*	*-0,92*
	Spearman	*0,94*	*-0,90*
8	Pearson	*0,82*	*-0,93*
	Spearman	*0,85*	*-0,91*
9	Pearson	*0,78*	*-0,94*
	Spearman	*0,76*	*-0,85*
10	Pearson	*0,45*	*-0,88*
	Spearman	*0,48*	*-0,88*

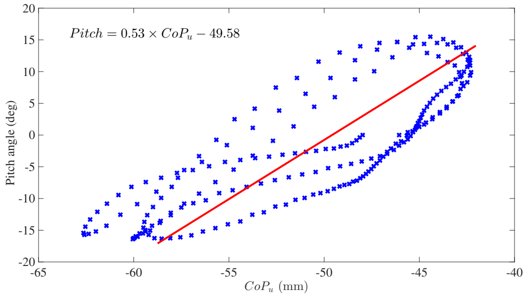

Fig. 3. Linear regression between the cane pitch angle and CoP_u

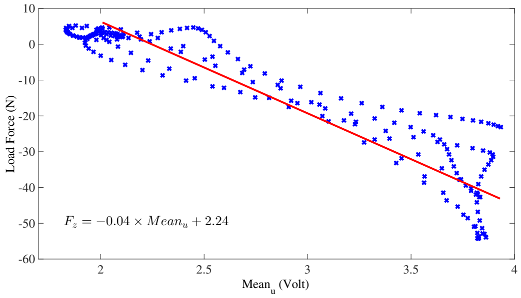

Fig. 4. Linear regression between the load force and $Mean_u$

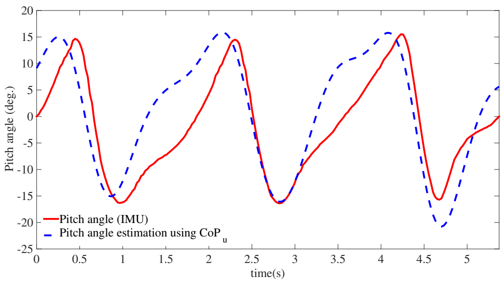

Fig. 5. Estimation of the cane pitch angle using CoP_u

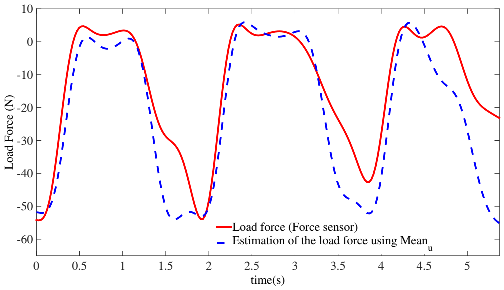

Fig. 6. Estimation of the force load using $Mean_u$

IV. CONCLUSION

In this paper a tactile sensor for cane use monitoring is proposed. It allows estimating both the cane shaft orientation as well as the load force applied on it. Th handle capabilities are shown through experiments involving ten subjects. As this tactile handle has pressure sensors on all its sides, it can also allow monitoring the grip force. The latter could be related to the fatigue level of subjects. The proposed handle could be a compact and cost-effective solution for monitoring users state in a robotic mobility aids context. It allows indeed to monitor at least three parameters with a limited complexity and space.

Future work include the corroboration of the given results during experiments involving more subjects. The six axis force sensor will be replaced by a load cell in order to allow an embedded processing on the cane and will avoid using wired data transmission. In this way, the cane could be used for longer walking distances and the robustness of the obtained results would be assessed.

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