Measurement and analysis of physical parameters of the handshake between two persons according to simple social contexts

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Abstract— **In order to facilitate and improve robots social acceptance, they must be equipped with behaviors similar to those of humans. It is therefore necessary to study and model the phenomenon to be reproduce. This paper studies and analyzes the physical parameters of the handshake in order to have its characteristic features (frequency, duration, strength, synchronization, etc.) used to model this interaction. Features that would later help to develop bio-inspired adaptive controllers, which will allow humanoid robots to better interact with humans according to simple social contexts.**

I. Introduction

Nowadays, technological developments favor the gradual use of robots in various fields of life. These robots are called to be more and more autonomous and perform tasks in dynamic environments constrained by interactions with humans. A question that arises is: to what extent is it useful or relevant to equip robots with behaviors similar to those of humans in other to improve social human-robot interaction and facilitate their (robots) social acceptance? Giving an answers to this question implies the lifting of several locks among which we can mention: interactions modeling, human beings cognitive phenomena modeling and learning phenomena modeling. Solutions to these problems will enable to design robots interacting with humans in different life situations such as: disability assistance, reception and presentation of art items, etc.

Among the usual activities of our daily life, the handshake carries a special significance as role involving interactions. It sets very often the first physical contact between two individuals. Beyond its ritual character of greeting, the latter is a gesture that involves a complex synchronization between the actors, not only at the level of member commitment, but also on the body in its entirety. The human-robot interaction by the handshake has been studied in robotics since 1996 [1]. In [1], [2], a handshake telephone system is proposed. It is a system with a haptic arm which allows two people to interact remotely receiving a haptic feedback. The telephone apparatus has a robotic arm (one degree of freedom) with a sensor force. The system records the user's handshake and reproduces it with a delay of about one second to a virtual partner. The handshake is performed with one or two oscillations of about $1Hz$ frequency. The force does not reach $10N$.

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The handshake has been more thoroughly examined by Jindai et al. who studied human interaction using quantitative measurements of the motion parameters. In their work [3] [4], the authors developed a mathematical model of the approaching phase (the hand movement before the physical contact) based on a model of movement made by humans. Indeed, the authors studied the first phase of the human handshake using five markers on the upper limbs (hand, wrist, elbow, shoulder of a subject's). By measuring the trajectories and the velocity profile of the hands, they established a mathematical model of the approaching phase by means of a transfer function. In [5], the models developed in previous works were revised to minimize the jerk during the execution of the movement of the robot. In [6] and [7], the team begins to take into account the second phase (physical interaction of the handshake), the rhythmic movement and uses a sensor strength on the robot wrist. Authors can thus study the rhythmic motion and contact of the upper limbs. The handshakes rebuilt between the robot and the human, based on the proposed models, have approximately the same features. In these papers, the physical interaction takes about $2.5s$ with a frequency of about $2Hz$.

Several other works have proposed controllers to perform a handshake with a robotic arm. In [8], the authors implemented a position-based admittance controller, where a high level controller receives haptic information used as input to a hidden Markov model. The aim of this controller is to estimate the human's intention in order to change the reference trajectory applied to the haptic device during the interaction. A low level controller uses this reference to perform the handshake and synchronizes itself to the human movement. In [9], the authors proposed a 'Turing test' to evaluate handshakes; where the average frequency was $2.5Hz+/-0.1Hz$. In the evolution of their work in 2012, [10] presented and compared three robot handshake models namely: 1) model called 'Tit-for-tat', based on the leader-follower roles and imitation; 2) Lambda model, based on physiological and biomechanical aspects; 3) Model 'IML-Shake', based on learning mechanism. The models 'Tit-for-tat' and 'IML-Shake' generated handshakes that were perceived as more human, but without significant difference between them. In [11], the authors represent the handshake in a cognitive context as a complex motor task that poses several challenges in the technical point of view of neuroscience. An experimental paradigm of their work is to investigate the correlations of handshakes between humans and between humans and robots using magnetic resonance imaging. A significant difference in the duration of the handshake was observed; $3,2s+/-0.27s$ for the handshake with the robot and $2.2s+/-0.49s$ for the handshake with humans.

In addition, in [12], an approach to the control of a robot arm based on the dynamic properties of a circuit oscillating neural networks is presented. In [13] the authors used a neural controller for synchronization during physical human-robot interaction. Neural oscillators are used to generate joint set for a synchronization between the movements of the human and the robot. The work presented in [14], offers an adaptive control method of human-robot interaction based on the prediction of the human intention. The study was performed on a theoretical basis, without experimental validation. The simulation of the behavior of the two arms indicates that synchronization appears very rapidly (between 0.2 and $0.3s$). It should be noted that the values of the initial frequencies are very close and high ($6.5-7Hz$). More recently, in [15], an adaptive kinematic controller for the human-robot handshake to achieve synchronization around $2s$ was proposed. The arm has an internal frequency of $1.5Hz$ and the synchronization is obtained by minimizing the power collected by the crawler.

In order to develop control strategies for humanoid robots to interact better with humans, we have seen that several controllers have been proposed in the literature to perform a handshake using a robotic arm. However, these controllers have been developed without the prior modeling and characterization of the phenomenon. These controllers have frequencies, durations, amplitudes and completely different response times from each other as shown in the literature review. In addition, some controllers consist in detecting and imitating the human motion (synchronize itself), thus moving away from the nature of the interaction. Melnyk et al. [16], [17] started to study the characteristics of a handshake between two people. From this study, it appears that a handshake between two individuals can be divided into four phases:

- the start of the handshaking; the hand movement before the physical contact (approaching phase),
- the physical contact without synchronization,
- the physical contact with synchronization (or mutual synchronization),
- the end of the handshaking.

Unfortunately, the acquisition system used in this work measures only the parameters of the wrist. As a continuity of Melnyk et al. work, the present work uses a precise contactless acquisition system in order to provide more reliable measurements of the physical parameters on all the joints of one hand (wrist, elbow and shoulder). The contribution of the present paper is to: finely study this interaction according to simple social contexts, characterize it to have objective elements (a benchmark) that allows the design of bio-inspired adaptive controllers to perform (reproduce) this interaction in given contexts. It is important to note that, behavior during a handshake can be influenced by relationships, gender, personality traits or culture (Western, Asian, etc). Qualitative studies such as [18], [19] address these aspects. In this paper, we assume that different couples know each other well and are in an environment where the handshake is a common gesture.

This paper is structured as follows. Section II presents the system used for physical parameters measuring and the tools used to analyze data. Section III presents results and discussions. Finally, we conclude in Section IV, with some remarks and future work directions.

II. Materials, method and tools

A. Physical parameters measuring system

This section presents the sensor architecture (Inertial Measurement Units, strength sensors) used to measure the physical parameters of the handshake between two people. This system provides more information for the better study and modeling of a handshake.

The acquisition system used is a wireless sensor network developed by the company TEA[1] for recording the movements, which are synchronized with video [20]. The measuring system used consists of 8 Inertial Measurement Units (IMU) and 12 strength sensors to measure the rotations of each joint (shoulder, elbow and wrist) and the contact forces between the hands. All data are stored synchronously at the frequency of $128Hz$. Fig. 1-(a) shows the sensors (IMU) positions. They are positioned so as to obtain the elementary movements of each joint. For the wrist; Abduction/Adduction and Flexion/Extension movements. For elbow; Flexion/Extension and rotation movements (Pronation/Supination). For the shoulder; Horizontal and Vertical rotations. Fig. 1-(b) shows the strength sensors positions on the instrumented glove.

(a)

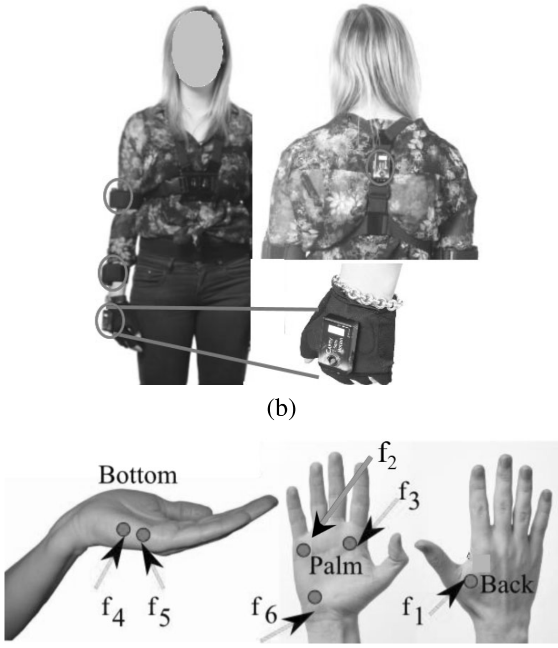

Fig. 1. Sensors positions: (a) Inertial Measurement Unit (IMU) positions (b), Force sensors positions on the instrumented glove

[1] http://teaergo.com/site/en/products/manufacturers/tea

B. Data collection methodology

Different people were equipped with sensors as described previously. Each experiment took about 15 minutes per couple and was overseen by a multidisciplinary team (roboticians and psychologist) to take into account both signal processing aspects and social context.

After welcoming participants, they where asked to exchange handshakes according to three different contexts:

- **Situation 1:** In this context, both participants are considered as colleagues and are asked to exchange handshakes in the morning saying 'hello'. We will call this greeting, ***Hello*** handshake.
- **Situation 2:** In this context, one of the participants has a happy event (success in an exam, etc.) and the other congratulates him/her by a handshake. We will call this greeting, ***Congratulations*** handshake.
- **Situation 3:** In this case, one of the participants is going through a painfull time and the other has to express his sympathy with a handshake. We will call this greeting, ***Sympathies*** handshake.

This protocol implicitly assumes that participants are or live in a Western culture where the greeting is very common. In all these situations, participants were asked to talk while shaking hands; Saying for example, *'hello', 'congratulations', 'sorry'*. For each situation, participants shook hands 5 times. They also simulated the various situations in an unchronological manner.

It is important to note that according to the protocol described above, handshakes are provoked (not natural). In future work, this protocol may be improved.

C. Data analysis tools

The judgment (valuation) of the social interactions is generally correlated with the level of synchronization of rhythmic movements between people. *Synchronization* can be defined as a rhythmic adjustment of oscillating objects in their interaction. Indeed, two oscillators with different frequencies and phases, mutually independent, can adjust their rhythm and begin to oscillate at a common frequency. This synchronization may be in phase or in anti-phase [21]. It is important to note that the mutual synchronization is not the only effect of an interaction. For example, if the coupling is very strong, it can cause the 'quenching' phenomenon; that is to say, the oscillations death.

Interpersonal synchrony refers to the temporal coordination between individuals in their social interactions. Originally studied by developmental psychologists, synchrony has now captured the interest of researchers in fields such as social signal processing, robotics, and machine learning. The manual and automatic tools found in the literature to assess the level of synchrony are presented in [22]. For automatic methods based on signal theory, we can distinguish: the correlation-based methods, the recurrence analysis based methods and spectral based methods.

In this work, to assess the level of synchronization between signals, we calculated at first their correlation over a sliding window. Then, we used a correlation peak detection algorithm to evaluate the degree of similarity between both signals. Afterwards, a normalization is made so as to have a value of one (1) in case of perfectly synchronized signals (in phase or anti-phase) and zero (0) otherwise. For more details, the method developed is very similar to that presented in [23] (Windowed Cross–Correlation).

III. Experimental results and discussions

The experiments were conducted in the LORIA Laboratory with a population of 44 people aged $19-66$ years, both men and women; 30 men and 14 women. These participants were an average age of 29 years with a standard deviation of 11 years. In this section, we will present the obtain results.

A. Collected data

The test campaign allowed us to collect data of approximately 400 handshakes made by 44 participants. In this section, we will present the data used at this stage of our research. Two particular handshakes of the first context ('Hello greeting') will be illustrated; a handshake with a low level of synchronization and a handshake with a high level of synchronization. Fig. 2 and 3 present each movements at the joints (of the two arms) and the sum of the contact forces of each hand respectively.

It is important to emphasize that we will present only the accelerations, velocities and angles of the main movements solicited during a handshake. Fig. 2 shows the acceleration, speed and angle of the wrist, elbow and shoulder of the two participants. We note that each participant have a distinct movement profile (see angles, speeds and accelerations). Such individual differences could reflect the particularity of each person (sequence of movements, posture, social skills, extra-version of personality and so on). All the joints are solicited during the handshake; the elbow angle variation is up to 100 degrees. In this scenario, participant 2 has the largest movements amplitudes (also observed on the contact forces).

Concerning the strength, the contact force gradually increase until a maximum (of about $10N$ for participant 2 in the second handshake), before decreasing thereafter. It can also be observed that the duration of the physical contact of each handshake is less than $1s$ (see Fig. 3).

B. Duration of handshakes physical contacts

We have studied the physical contact durations for the 400 handshakes performed in three different social contexts. The first context is a daily regular greeting. The second is a greeting to congratulate and the last is a kind greeting to express sympathy in a painful situation. Fig. 4 shows the different durations of physical contact functions in different contexts for each of the studied couples. The various handshakes relatively have the same variation range of the physical contact duration. This duration varies from 0.65 to $2.28s$. However, handshakes have different distributions (mean and standard deviation) depending on the context. For

‘Hello’: $0.9s+/-0.26s$, ‘Congratulations’: $1.24s+/-0.4s$ and $1.3s+/-0.49s$ for ‘Sympathies’.

It is clear that a ‘Hello’ handshake is shorter than a ‘Congratulations’ or ‘Sympathies’ handshake. The average difference with a standard ‘Hello’ greeting is $+37\%$ for ‘Congratulations’ or $+44\%$ for ‘Sympathies’. In terms of duration of physical contact, these results may allow us to distinguish two types of handshakes: **Short** (‘Hello’) and **Long** (‘Congratulations’ or ‘Sympathies’). Besides this classification, the hovel of these times provides us with important information for the design of controllers; in fact, the response time of the controllers to be developed must be less than the duration of the physical interaction. This response time includes the robot and humans movements synchronization time.

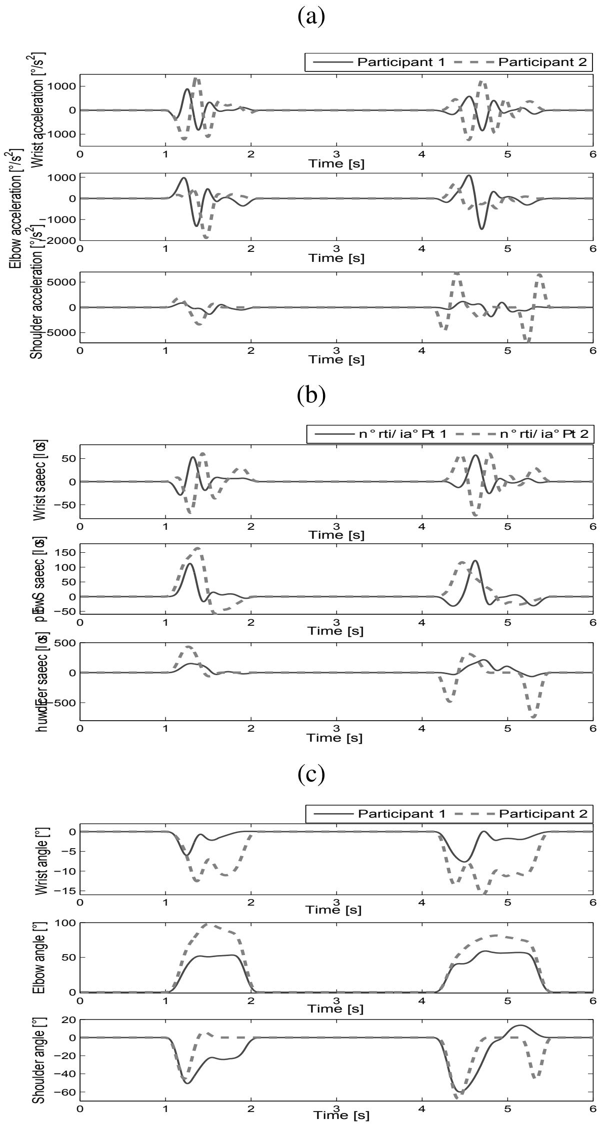

Fig. 2. Joint movements: (a) Accelerations (b), Speeds, (c) Angles

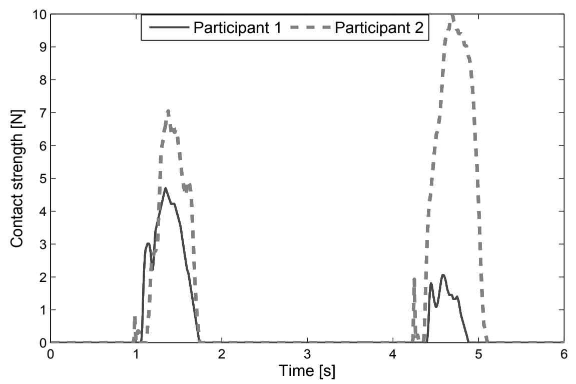

Fig. 3. Contact strengths of the handshake

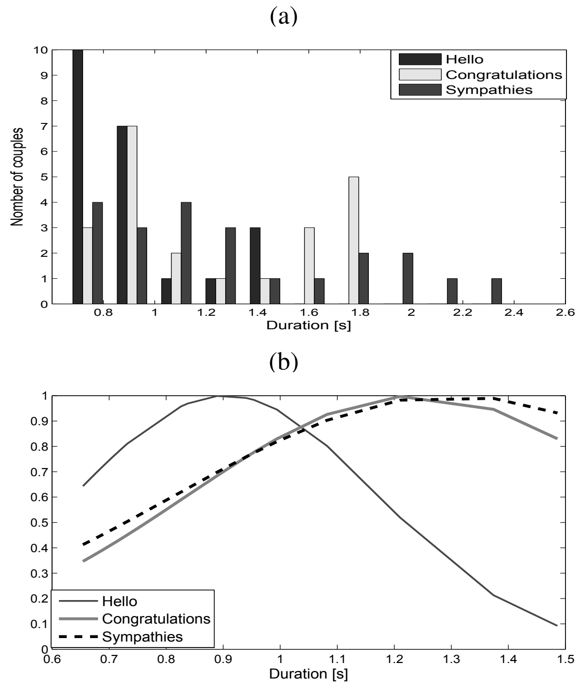

Fig. 4. Duration of physical contact of handshakes: (a) Histogram, (b) Distribution of durations

C. Contact forces of handshakes

The contact force during a handshake strongly depends on the person and the life situation. We propose here, to observe and analyze the contact force of different handshakes depending on the context.

Fig. 5 presents the distribution of the maximum force average of the performed handshakes. It appears that the maximum force varies between 0.5 and $14.5N$. The different handshakes have different characteristics; ‘Hello’: $4.37N+/-2.4N$, ‘Congratulations’: $5.88N+/-3.2N$ and ‘Sympathies: $3.12N+/-2.1N$. It appears that ‘Sympathies’ handshakes solicit lower amplitude forces. ‘Congratulations’ handshakes have the most important contact forces. The distribution of forces can help to classify the handshakes into three categories; **Low**, **Medium** and **High**.

In these first analysis, it is clear that the contact time duration is approximately $1.15s$ and the average force is

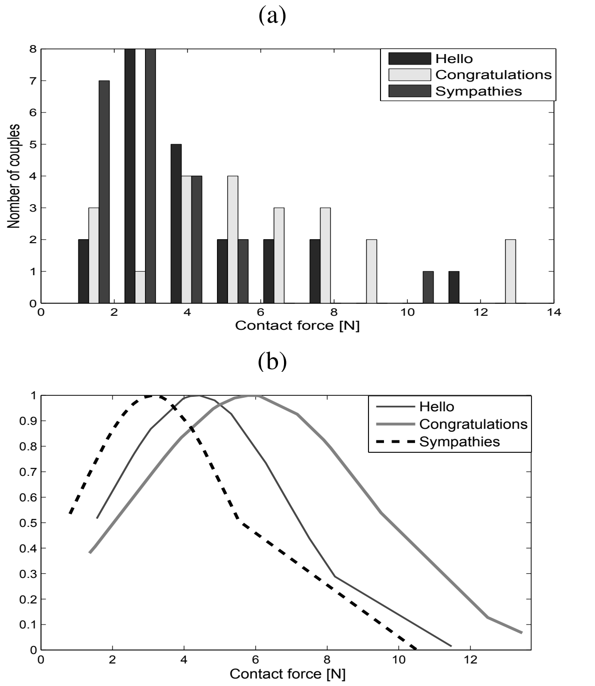

Fig. 5. Average maximum strength of handshakes: (a) Histogram, (b) Distribution of strengths

around $4.46N$. The context has an important effect on the strength and duration. Table I summarize the various elements observed which can be used as a reference for designing bio-inspired adaptive controllers.

TABLE I

SUMMARY OF RELATIONS BETWEEN THE STRENGTH, DURATION AND TYPE OF HANDSHAKE

Force / **Duration**	Low	Medium	High
Short	-	Hello	-
Long	Sympathies	-	Congratulations

D. *Main frequency of various arm joints*

The distribution of the main motion frequency of each joint (wrist, elbow and shoulder) has been studied for different handshakes (Table II). According to Table II, it is clear

TABLE II

MAIN FREQUENCY OF VARIOUS ARM JOINTS

	Hello	**Congratulations**	**Sympathies**
Wrist	$2.43Hz+/-0.62$	$2.66Hz+/-0.72$	$2.44Hz+/-0.69$
Elbow	$1.95Hz+/-0.55$	$2.09Hz+/-0.77$	$2.11Hz+/-0.63$
Shoulder	$2.4Hz+/-0.94$	$2.07Hz+/-0.78$	$2.37Hz+/-0.79$

that all joints (wrist, elbow, shoulder) are solicited during the handshake. The average frequency of the joints are similar and the context has a little influence on the movement main frequency. This implies that, to reproduce this interaction by a robotized arm, inspired by nature, it would be appropriate to have a robotic arm with several degrees of freedom to better approximate the human behavior.

E. *Synchronization evaluation*

When considering the case study of the synchronization between different joints' movements of two arms engaged in a handshake, several questions arise: Do humans often have mutual synchronization during a handshake? On which joint can synchronization be measured in a better way? Are the different joints's movements highly correlated? In order to start answering these questions, we have calculated the level of synchronization between the different joints signals using the tool presented in paragraph II-C. Fig. 6 shows the assessment of the synchronization level of the (wrist, elbow and shoulder)'s signals (acceleration, speed and angle) of both participants. As shown in Fig. 6, we observe that for the first handshake (time interval between 1 and 2 seconds), the level of synchronization is almost 0 at the handshake beginning. After about 0.4 seconds, the synchronization level increases and remains constant during the rest of the physical interaction. The level of synchronization is low at the wrist (acceleration speed and angle). Contrary to wrist, the synchronization at the shoulder is high. On the elbow, a low level of synchronization is observed on the acceleration and speed, while it is high in the angle. It is apparent that during this handshake, synchronization occurs after a certain time from the beginning of physical interaction.

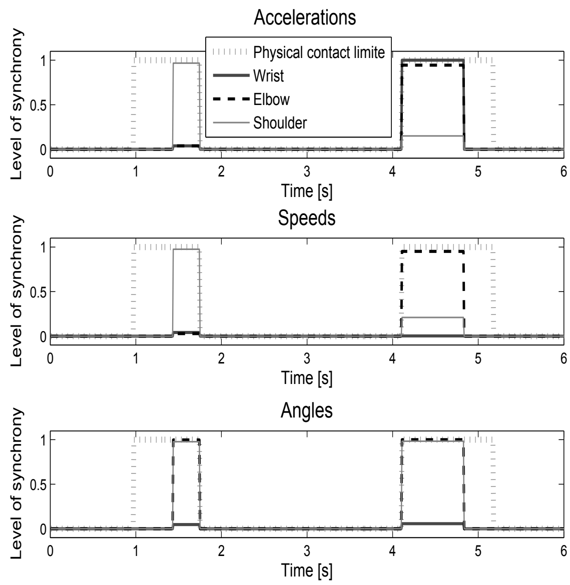

Fig. 6. Synchrony evaluation

Regarding the second handshake (approximately between 4 and 5 seconds), we note a high synchronization level (almost equal to 1) from the beginning of the physical interaction on the acceleration of the wrist (Fig. 2-(a) presents the acceleration of both wrists to better observe the temporal signals). Here, it is during the end of the physical interaction that the level of synchronization drops. In this handshake, the level of synchronization of the elbow is high. It is important to note that these two handshakes were made by the same pair of participants simultaneously.

From these preliminary results, we note that the synchronization levels are different in the arm joints (wrist, elbow, shoulder). More so, the level of synchrony varies depending on the evaluation signal (acceleration, speed or angle) on the same joint. Hence, it is difficult at this stage to identify relevant conclusions. The analysis of synchronization on all 400 handshakes performed is been conducted and will allow us to observe relevant behaviors and characteristics.

After this analysis, how can these information be translated to efficient human-robot handshake operations? To give an answer to this question, we can say at this stage of our research that a bio-inspired handshake can be modeled by an oscillatory motion (controller) with an initial frequency of $2.5Hz$, amplitude and length depending on context. In addition, the controller must be able to synchronize within $1.5s$ after physical contact with humans.

IV. Conclusion

In order to develop control strategies to enable humanoid robots to better interact with humans, several controllers were already proposed in the literature to perform a handshake with a robotic arm. However, these controllers have been developed without the modeling and the characterization of the phenomenon (the interaction). This paper has studied the physical parameters of the handshake, considering several simple contexts of daily life; 'Hello', 'Congratulations' and 'Sympathies' greetings. Considering the experimental results, it appears that, the main frequency of the joints (wrist, elbow, shoulder) are similar and is little influenced by the context. More so, the context have an important effect on the strength and duration of the handshake. In addition, knowledge of these parameters and magnitudes is a benchmark for studying and designing controllers; in order to perform this interaction by a robotic arm. These results also show that, the study of the synchronization is different depending on whether the study is done at the wrist, the elbow or the shoulder. At the same time, the evaluation of synchrony give different results depending on the signal used (acceleration, speed or angle).

As outlook, we intend to improve the experimental protocol and extend the study to other contexts for more precised, varied and representative data. We know that the behaviors of handshake could differ between men and women and also between same-gender and opposite-gender. We did not analyze the effect of gender in this previous study and would like to finely consider this aspect.

More so, we will continue with a theoretical study of the synchronization of dynamic systems in interaction. We are developing models for adaptive controllers in order to perform this interaction with a robotized arm according to simple social contexts.

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