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Tactile interaction with a humanoid robot for children with autism: A case study analysis involving user requirements and results of an initial implementation

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Abstract— **The work presented in this paper is part of our investigation in the ROBOSKIN project. The project aims to develop and demonstrate a range of new robot capabilities based on the tactile feedback provided by a robotic skin. One of the project's objectives is to improve human-robot interaction capabilities in the application domain of robot-assisted play. This paper presents design challenges in augmenting a humanoid robot with tactile sensors specifically for interaction with children with autism. It reports on a preliminary study that includes requirements analysis based on a case study evaluation of interactions of children with autism with the child-sized, minimally expressive robot KASPAR. This is followed by the implementation of initial sensory capabilities on the robot that were then used in experimental investigations of tactile interaction with children with autism.**

I. INTRODUCTION

TOUCH is a key element in social development. The need for human contact starts from the moment a baby is born. Various studies have shown that skin-to-skin contact of mothers with their newborn babies has a long lasting effect in later stages of life on the children's intelligence and comprehension. Touch deprivation in early stages, can lead to speech retardation, learning disabilities as well as emotional problems in later life [1-3].

Physical touch is one of the most basic forms of communication. Human sense of touch can be divided into two different categories, cutaneous and kinaesthetic. While the former relates to sensing using the skin's mechanoreceptive nerve endings to detect small-scale details such as skin stretch, compression and vibrations, the later relates to large-scale details such as basic shapes and mechanical properties, for example compliance, perceived using the musculoskeletal system. These both form the basis of human touch. In the playground, physical contact is used by children to communicate with each other, to build trust, to give or receive support and to develop their social relationships. In recent years various robotic systems have been developed to research and promote social interaction skills and mediate interaction for people with and without cognitive and/or physical impairments. Artificial pets such as the baby seal Paro [4] [5], the teddy bear Huggable [6], the cartoon-like robot Keepon [7] and humanoid robots such as the robotic doll Robota [8] [9] [10] and the child-sized robot KASPAR [11] were designed to engage people in personal experiences stimulated by the physical, emotional and behavioural affordances of the robot. This is a growing area of research with potentially great benefits for people with special needs.

In earlier studies, Salter et al [12] studied the touch patterns of children with autism on a mobile robot, which was equipped with 15 infrared sensors. The sensor readings were analysed to classify tactile behaviours of different children, and were consistent with the initial psychological classification of the children. In [13], Francois introduced a real-time method recognizing different types of touch, using the Cascaded Information Bottleneck method. This work focused on time series data, relying on the principle that relevant information can be progressively extracted from a data sequence over time. The importance of using quantitative tactile data has been emphasized in both of the above work for developing natural human-robot interfaces.

In this paper we first present a preliminary study that identifies user requirements based on case studies evaluating the interaction of children with autism with the child-like robot KASPAR. We identify and categorize different types of touch, with variable degrees of pressure and asserted force, measured during the child robot interactions. We then enhanced KASPAR with tactile sensors and conducted trials of children with autism interacting with the robot. In future we intend to use such data from skin, along side kinematic data from robot joints, as well as video analysis in order to further augment tools for analysis and design of interaction of KASPAR with children with autism.

A. Autism and tactile interaction

Autism here refers to Autistic Spectrum Disorders, a range of manifestations of a disorder that can occur to different degrees and in a variety of forms [14]. It is a lifelong developmental disability that affects the way a person communicates and relates to people around him. The main impairments that are characteristic of people with autism lie in the areas of social interaction, social communication and social imagination [15].

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Moreover, people with autism usually exhibit little reciprocal use of eye-contact and rarely get engaged in interactive games. They have difficulties in understanding gestures and facial expressions, difficulties with verbal and non-verbal communication, and are usually impaired in understanding others intentions, feelings and mental states.

Some people with autism have hyper-sensitive sensory conditions [16]. Hypertactility is very common [17] and results in overwhelming sensation. As touch can be excruciating they fear being touched. This fear could be so strong, it can cause a panic attack [16], others might be hyposensitive. Those with hypotactility seem not to feel pain or temperature and e.g. may seem unaware of a broken bone. In day-to-day interaction, their touch of other people or objects would not be perceived by them and unintentionally they could hurt other people, or break objects. A dysfunctional tactile system may also lead to self-imposed isolation.

In our work we argue that a 'tactile' robot can be used at a basic level as a mediator i.e. an extension of a therapist or another person or a buffer that mediates by indirect contact, until such time that the person builds enough strength and confidence to tolerate direct contact with another person.

The nature of touch is very individual to a person and so a robot with tactile sensing must take into account individual needs and differences and should adjust its behaviour accordingly. It also could allow a person with autism to explore touch in a way which could be completely under his control. The next section describes preliminary trials of children with autism playing with KASPAR, studies that helped to identify user requirements for tactile human-robot interaction.

II. THE TRIALS

The trials described in this paper took place in two special needs schools for children with moderate learning difficulties in the UK. The trials were designed to allow the children to get used to the presence of the investigator, get familiar with the robot and to have unconstrained interaction with the robot with a high number of degrees of freedom, should they wish to. Our objective was to provide a reassuring environment where the repetitive and predictable behaviour of the robot is a comforting factor and where the children could have opportunities for free and unconstrained interactions with the robot and with the present adults (i.e. teacher, experimenter) should they choose to. These trials we refer to as the "main" trials throughout this paper.

Alongside these trials, we conducted a separate experiment with 5 healthy volunteers in the lab, in order to judge suitability of sensor positioning and sensor sensitivity to different levels of touch. Some of our findings from this second experiment are also reported in this paper. We refer to this as our "laboratory experiment".

A. The Robotic Platform - KASPAR

KASPAR is a child-sized robot which acts as a platform for Human-Robot-Interaction studies, using mainly bodily expressions (movements of the head and arms) and gestures to interact with a human. It is a 60 cm high robot is fixed in a sitting position (see Fig. 1). The main body of the robot contains the electronic boards, batteries and motors. KASPAR has 8 degrees of freedom in the head and neck and 6 in the arms. The face is a silicon-rubber mask, which is supported by an aluminium frame. It has 2 DOF eyes fitted with video cameras; eye lids that can open and shut and a mouth capable of opening and smiling. It has several pre-programmed behaviours that includes various facial expressions, hand waving and drumming on a tambourine that is placed on its legs [18].

To help characterize the child-robot physical touch and to help create tactile play scenarios, the robot was equipped with tactile sensor prototypes placed on several points on the hands, arms, shoulders and head (see Fig. 2).

Fig. 1. The robotic platform KASPAR .

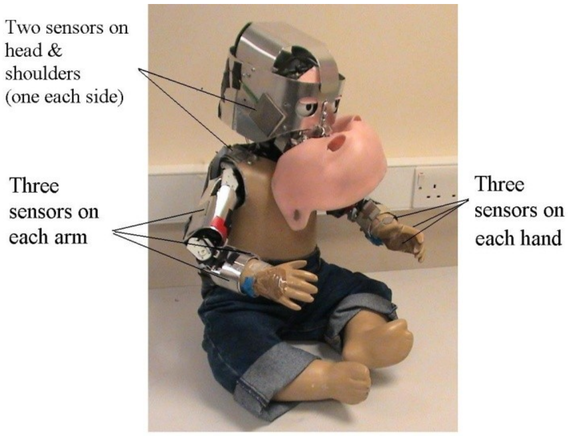


Fig. 2. Illustration of the temporary tactile sensors

Pressure/force sensors are available in different forms. As a primary objective of this project, new sensing technology based on piezoelectric and capacitive effects is being developed and will be available to us later in the project. To allow for preliminary investigations using tactile sensors and tactile interaction, force sensitive resistor (FSR) sensors were employed. Preliminary testing and the specification of such sensors (see Fig. 3) have shown promising sensitivity for this application. Compared to other sensing technologies, FSR sensors require a relatively simpler electronic interface and provide an affordable solution. As they are available in thin and flexible forms, they can be mounted on the robot at different locations. Fig. 2 shows the sensors on KASPAR at 16 different locations. These locations were selected based on observations of previous studies with children with autism (cf. Section III). The signals are acquired using a micro-controller with an additional multiplexer circuit to extend the number of analog channels. Regarding the FSR sensitivities, Fig. 4 shows four typical signal samples acquired using both left and right hands from one adult, touching the sensor lightly and forcefully as a preliminary test for the sensor's suitability.

Based on Guclu and Oztek's study of children's tactile sensitivity [19], it is suggested that the tactile sensitivity frequency of interest in general concentrates on the range between 2Hz to 500Hz. In this work, due to the limited bandwidth of RS232 port, signals are sampled at 60 Hz continuously and logged into files for later off-line analysis. According to the preliminary test described above, the sampling rate was found to be adequate for this application.

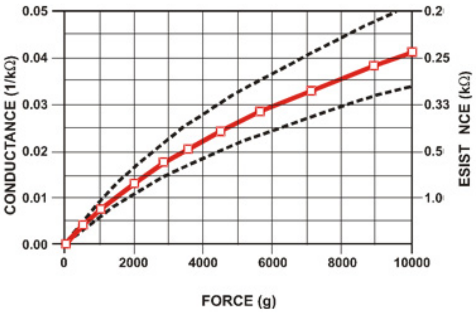


Fig. 3. Resistance vs. Conductance (taken from: www.interlinkElectronics.com)

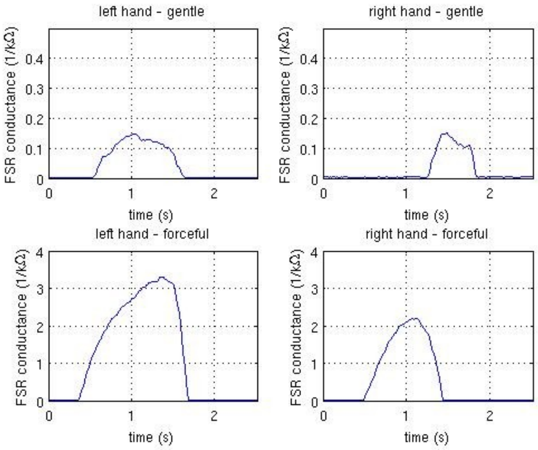


Fig. 4. Four typical signals performed using both left and right hands, gently and forcefully

B. *Main trials set-up & procedures*

The trials took place in two schools in the UK (Woodland school in London and Tracks in Stevenage). The trials were designed to allow the children to have unconstrained interaction with the robot. The trials were conducted in a familiar room often used by the children for various activities. Before the trials, the humanoid robot was placed on a table, connected to a laptop. The investigator sat next to the table. The robot was operated remotely via a wireless remote control (a specially programmed keypad), either by the investigator or by the child (depending on the child's ability). The children were brought to the room by their carer and the trials stopped when the children indicated that they wanted to leave the room or if they became bored. Two stationary video cameras were used to record the trials.

III. USER REQUIREMENT ANALYSIS

Based on initial video analysis of interactions of 3 children with autism interacting with the KASPAR robot (without tactile sensors at this stage), Table I below shows very typical and frequently occurring touch interactions that are very relevant in this application domain. It highlights the types of touch that need to be detected and provides preliminary requirements for the development of new skin technology and tactile recognition algorithms for these types of child-robot tactile interaction.

TABLE I

CHARACTERISTICS OF TYPICAL TOUCH INTERACTION OF CHILDREN WITH AUTISM WITH THE KASPAR ROBOT

Behaviour/action	**Duration of contact**	**Intensity of forces applied**	**Spatial Expansion**
Child grasps robot's wrist-Cylindrical grasp	Extended	Tight grip	Full grasp
Touch forehead to robot's forehead	Brief or extended contact	Very gentle touch	Localized
Child touches robot's nose with his forehead	Brief	Moderate touch	Localized
Child gently holds robots face/ hands around the robot's cheeks	Extended	First gentle touch, then squeezing	Cover large areas of robot's face
Child kisses robot on its lips	Brief	Gentle touch	Localized
Child encloses with both hands one of KASPAR's hands	Brief	Gentle touch	Extended (both sides of robot's hand)
Child touches	Extended	Gentle	Limited

robot's foot		touch	
Child rests his hand on robot's foot	Extended	Gentle touch	Limited
Child grasps fingertips of robot's hands, whilst moving it- Pinch grasp.	Extended	Gentle touch & movement	Localized
full hand to hand grasp	Extended	V. gentle grasp	Extended
Gentle touch both hands to hands and moves hands	Extended	V. gentle touch & movement	Extended
Poking with one index finger in /around robot's eye	Brief	Very gentle touch	Localized
Child repeatedly strokes robot's cheek with his fingers	Brief -fast movement	Very gentle touch	Extended
Fingers stroking repeatedly strokes robot's chin	Brief -fast movement	Very gentle touch	Localized
Hand stroke robot's forehead	Brief	Very gentle	Extended
Tap of finger to robot's hand	Very brief	Moderate	Very localized
Pinching both cheeks of robot with hands	Extended	Forceful	Extended
Child grasps robot's hands with his hands and pulls robot towards her	Extended	Forceful	Extended
Child pokes both cheeks of robot with her index fingers	Extended	Forceful	Localized
hands on robot's upper arms/shoulders	Extended	Forceful	Extended

A. Summary Of User Requirements And Case Study Examples

Three main types of touch using the hands can be identified: grasping (including lateral pinch, pulp pinch, chuck pinch, four finger pinch and five-finger pinch), stroking, and probing and poking (see Fig. 5). Children also used their head and face to touch robot's forehead, face and lips (see Fig. 6). This was a very interesting observation as studies often concentrate on touch via hands (i.e. grasp and poke force exertion) as parameters influencing ergonomic design for tactile sensing [20]. Intensity of touch varied between 'tight' to 'very gentle' touch, where tight grip was identified when children used their whole hand to tightly grasp the robot's hand and 'very gentle' was the case when robot's finger was grasped gently using a pinch grip. The robot's hands, wrist, face, eyes, forehead, and feet were often touched during the interaction. Our experimental setting did not allow children to lift KASPAR or to hug KASPAR thus other types of touch such as hugging are omitted from our possible scenarios. The duration of contact varied between very brief (smaller than 1 second) to brief (between 1 and 2 seconds) and extended contact (greater than 2 seconds).

Fig. 5. Typical types of interaction: grasping (left), stroking (centre), poking (right).

Fig. 6. Using head and face to touch the robot (left image shows child kissing the robot)

B. Additional User Requirements:

Based on our observation and analysis of the videos, the following additional observations are made regarding interaction in more general terms:

- Simultaneous actions may happen (e.g. poking a cheek while resting one hand on the robot's foot)
- It would be highly desirable to detect skin deformation that occurs frequently during poking/squeezing/pinching actions etc.
- Spatially extended actions occur frequently: it is important to get the raw data (forces/contact etc., rather than averaged or higher-level summarised data) across the whole area (the distribution of forces along the surface concerned. Such data can be very relevant for the application area of robot assisted play in therapy or rehabilitation.

IV. SENSING RESULTS AND ANALYSIS

To help us built appropriate tactile play scenarios, a series of experimental investigations has begun to find out how the above requirements can be best implemented. KASPAR was equipped with temporary tactile sensors to try to capture the characteristics of any tactile interactions that may occur. Results of these trials highlighted the challenge to provide accurate sensing mechanism that can detect such a variety of types of interactions e.g. a very gentle hand stroke on the robot's face, a gentle hand grasp of the robot hands, a gentle kiss on the robot's lips (see examples in Fig. 7).

Fig. 7. Variety of tactile interactions: gentle grasp of both hands (L), gentle grasp of arm (C), kissing (R)

A. *Laboratory Experiment With Healthy Volunteers*

Five healthy volunteers were instructed to interact with the robot in a play scenario, forcefully and gently. Results obtained from this interaction were analysed in order to further investigate touch patterns and spatial resolution of the sensors, Fig. 8 shows two signal patterns, which were extracted from the left upper arm sensor available for one volunteer, in gentle and forceful manners respectively.

As observed in Fig. 8, to some extent, the force amplitudes could reveal the difference between two types of touch for one individual using a specific sensor. Both groups have shown strong variations of forces from the fluctuating observed data. This indicates that the FSR technology does not allow to distinguish the two types of touch between all participants using only the force amplitudes. Such difficulties are explained by the perception differences in individual people when asked to interact forcefully and gently. Table II shows the comparison of data from the 5 healthy volunteer adults. The forces from all 16 sensors (relative conductance based on Fig. 3) were pre-filtered to remove the DC components due to existence of pre-loaded sensors (those in contact with other part of robot body, for example when robot arm was resting on its lap), and only those values above a pre-defined positive threshold were taken into consideration. It can be seen that the hard touches in general have higher values than the corresponding soft touches. However, as stated above, different people's force levels vary significantly. In addition, the mechanical compliance of the robotic mechanism is another cause of the variation of force levels as for example, our back-drivable robotic arms moved when subjected to strong forces.

TABLE II
COMPARISON OF SOFT AND HARD TOUCHES BY 5 VOLUNTEER ADULTS

People	*Soft (1/kΩ)*		*Hard (1/kΩ)*	
	Avg	Max	Avg	Max
1	0.098	0.738	0.131	1.202
2	0.126	1.633	0.167	2.155
3	0.073	0.786	0.079	0.722
4	0.0082	0.0924	0.0211	0.4724
5	0.0503	0.5283	0.0784	1.4504

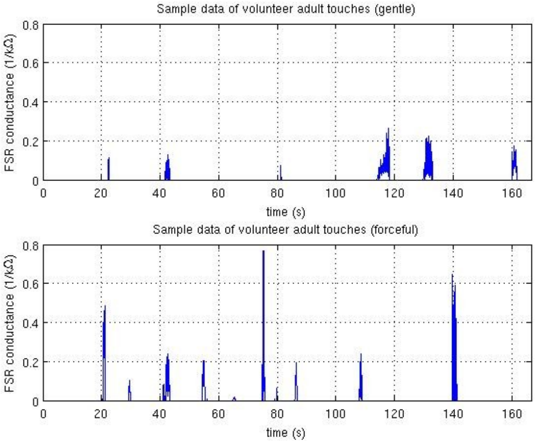


Fig. 8. Sample data of gentle and forceful touches by a volunteer adult

Fig. 9 and 10 show the play patterns on different locations over the whole period of the play session, performed by one adult in forceful and gentle manners respectively. The top part of the figure presents sensed touch by each sensor as time passes while the bottom part presents an integral of sensed forces for each sensor. Table III lists the description of each sensor index as shown in Fig. 9 and 10.

TABLE III
SENSOR LOCATIONS AND INDEXES

Sensor index	*Sensor location*	*Sensor index*	*Sensor location*
1	Left face	2	Right face
3	Left Shoulder	4	Right Shoulder
5	Left upper arm	6	Right upper arm
7	Left forearm – 1	8	Right forearm – 1
9	Left forearm – 2	10	Right forearm – 2
11	Left Wrist	12	Right Wrist
13	Left hand back	14	Right hand back
15	Left hand palm	16	Right hand palm

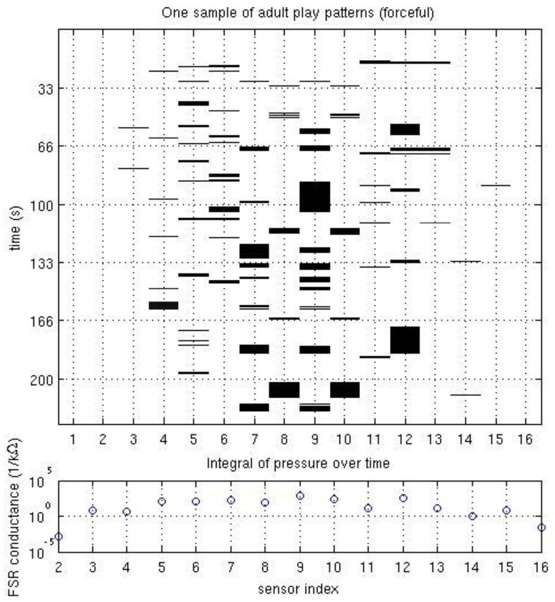


Fig. 9. Sample adult play pattern (forceful)

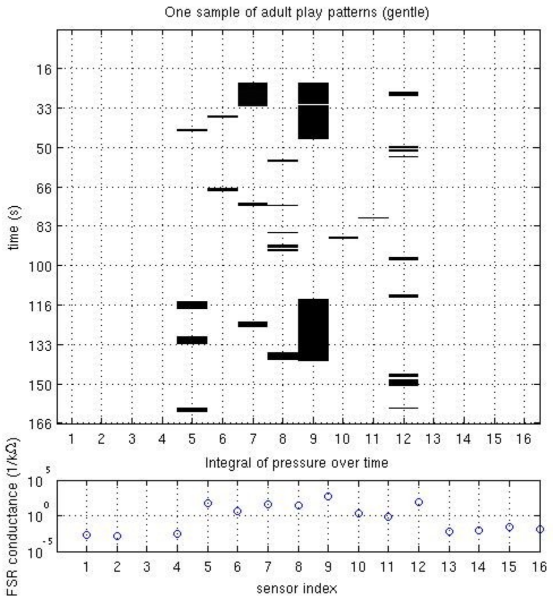


Fig. 10. Sample adult play pattern (gentle)

B. *Results of Main Experiment*

A long-term objective of our study is to be able to identify different types of touch (as presented in Table I) using the sensor technology developed during this project. However, since the new sensor technology will only be available to us at a later stage in the project, the present study conducted preliminary investigations to further explore sensor positioning and sensory reading during interaction with children with autism.

Fig. 11 shows two typical signal samples acquired during one play session from two forearm sensors (left and right respectively), where tactile contacts occurred more frequently for this particular child. The children were not advised to conduct tactile interaction with KASPAR during the play sessions. These two figures reveal the basic information of how frequent tactile interactions occur. In general, it is found that children tend to focus on one specific part of the robot at one time. However, for KASPAR's hands, simultaneous tactile interactions on both the robot's left and right hands are observed to happen more frequently, as shown in Fig. 12. Fig. 11, 12, and 13 show that it is possible to detect length, location and extent of touch using each sensing unit.

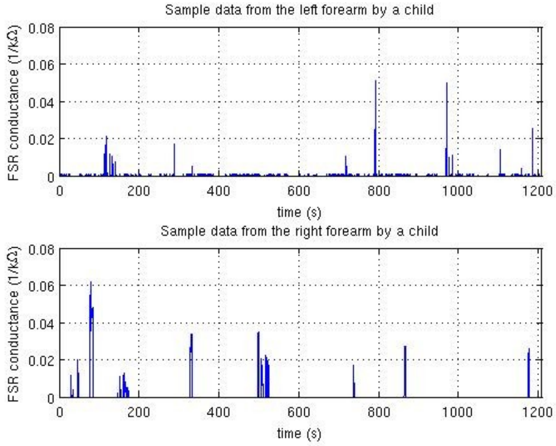
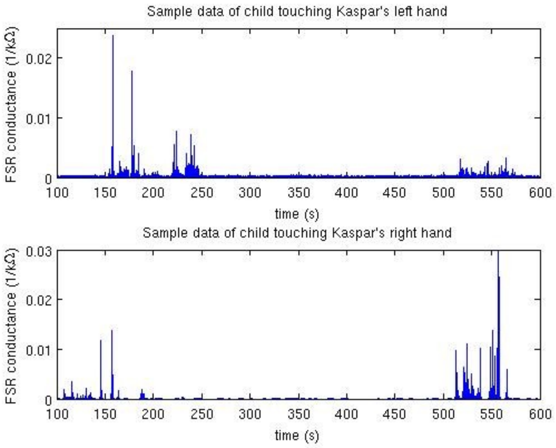


Fig. 11. Sample data of two forearm sensors (left and right), acquired during



a

play session with a child

Fig. 12. Sample data of two hand sensors (left and right), showing the child simultaneously touching both of KASPAR's hands.

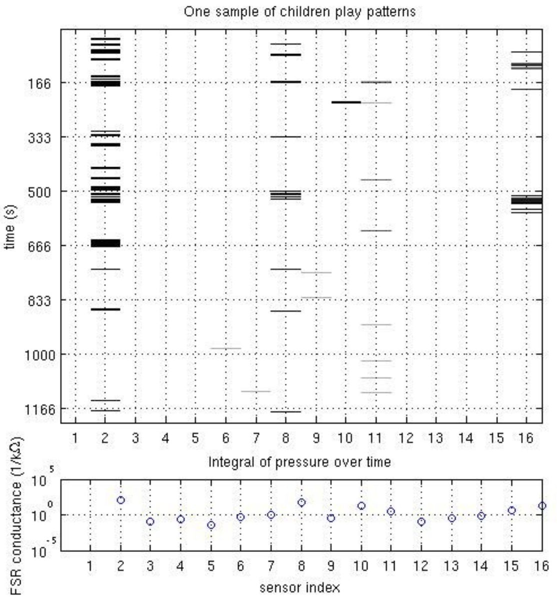


Fig. 13. Sample child play pattern

V. DISCUSSION AND FUTURE WORK

This preliminary study presented the challenge in capturing the variety of tactile interaction that is characteristics to children with autism. Our future work will continue with experimental investigations to find ways to capture more of these tactile interactions, and to devise tactile play scenarios that a) will be based on these interactions and b) will be built against the specific therapeutic or educational needs of children from this user group.

This paper presents our study in using tactile interaction in the context of robot-assisted play with children with autism. The work consists of three components, sensing requirement analysis, sensor integration and preliminary testing of the sensing capabilities. Table I presents our finding for sensing requirements based on video analysis of the interactive sessions with 3 children with autism. Part of these findings was used to position sensors at different parts of the robot body. Our study then continued by trialling the KASPAR robot, augmented with FSR sensors, in two contexts, with healthy adult volunteers and with 3 children with autism. While this study is still at its early stages and further experiments are on the way, our findings showed that healthy adults could exert variable levels of pressure when instructed to do a firm or light touch. However, FSR sensors were able to identify a cut-off point of about 0.6 N for firm (above threshold) and light (below threshold) touch.

Our main study concluded that it is possible to identify robot body parts that are subjected to touch, and moreover, it is possible to identify touch duration, maximum or average level of pressure or integral of sensed touch during a contact. Our current experimental setting allows to further investigate tactile features during interaction, and our aim is to complete Table I with sensed quantities matching those observed during video analysis.

Further investigations are planned to learn more about the spatial resolution and sensitivity of these sensors. In order to recognize patterns of touch (e.g. gentle versus forceful) different techniques may be investigated, including the unsupervised Self-Organising Maps (SOM) method [19], cascaded information bottleneck method [13], and a rather basic but effective method using a hybrid sensor combining shock and pressure sensors [21]. On the other hand, however, due to the sparse sensor coverage and unpredictable behaviours of children, tactile interaction could not be adequately captured with the current setting. The partial measurement of sensor data makes this problem ill-posed and difficult. This can be resolved with the planned sensors achieving more spatial coverage to some extent in the future, and thus improve the recognition accuracy.

As interaction analysis is multimodal, as shown in [22, 23], in our future studies we intend to merge conventional video analysis techniques with tactile data captured during the interaction (both cutaneous and kinaesthetic) in order to aid both the analysis and shed new light on both objective and subjective interaction measures.

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