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IMPROVEMENT OF PNEUMATIC FOOTBALL KICKING DEVICE BASED ON IMITATION OF HUMAN DYNAMICS

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Abstract: *Imitation of the explosive human dynamics has been proven challenging to replicate with mechanical devices. Kicking movements can be created by a device where the motions are replicated with fluidic muscles. The goal with this research is to improve the usability and dynamics of the football kicking device to meet the speed and accuracy of the football to match a human kick. The research platform is a football penalty kick training device, able to perform a kick with adjustable speed and direction. The mechanical structure of the kicking element was built to resemble a human leg. Improvements were achieved in speed, accuracy, reliability and usability. This study shows that human dynamics can be imitated to some extent by using fluidic muscles.*
Key words: fluidic muscle, training device

1. INTRODUCTION

In recent times, huge leaps have been taken to replicate movements of the human body. A good example of this kind of replication is the Honda humanoid, Asimo [1]. As this humanoid robot mimics movements of the human body, however the movements achieved are fairly slow compared to the explosive dynamic performance achieved by human beings. Boston Dynamics have also replicated the dynamics of human body for example in their humanoid robot Petman [2]. Furthermore, Adidas has developed a device that utilizes a real shoe to shoot the ball as in the research [3].

It is this kind of high-level human performance that is investigated in this study in the form of a football kick. The aim is not to concentrate on imitating human anatomy or the complete kick movement of the human body, but the dynamics involved in kicking a football. While the Asimo robot is able to kick a football, both accuracy and speed of the kick is low compared to a kick made by a human. According to a research done by Lees and Nolan, the speed of a football can reach 100 km/h when kicked by a professional football player [4]. The same research however states that the speed of the ball decreases when there is a higher demand for accuracy. The target for the accuracy in their research was set to a 1 x 1 m area in the top right corner of a football goal. For the kicks that met the accuracy requirement the speed of the football dropped to around 75 km/h.

A research have been made using fluidic muscles to power the artificial leg and the setup from that research is used as a base for the research done in this paper. [5] The previous research proved that pneumatic muscles can be used to achieve fairly accurate and powerful football kicks.

The goal of this research is to further develop the pneumatic leg to achieve a higher top speed and higher accuracy of the kicked football. The requirements for the kick by the pneumatic leg in this research are the same as in the research done by Lees and Nolan, i.e. to achieve a top speed of 100 km/h and an accuracy of hitting a 1 x 1m area from a distance of 9 m.

The dynamics involved in the pneumatic leg are the rotational movement of the upper and lower leg in the direction of the kick (Fig. 1). The goal is to replicate the structure of a human leg. However, the rotational movement in other directions, such as twisting of the leg around its own axis, is not investigated in this paper.

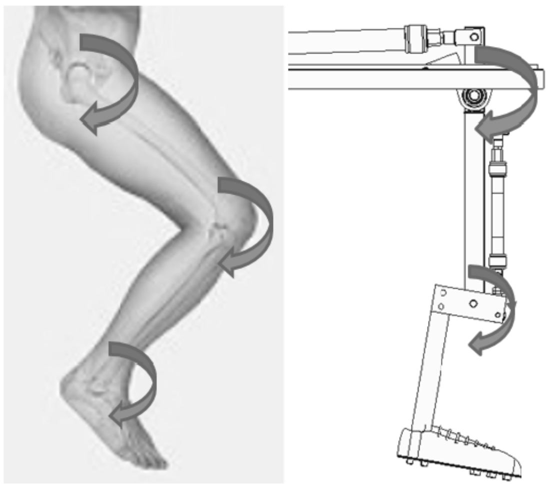

Fig. 1. Human leg joints and movements in comparison to the device.

In addition to the higher performance pursued in this research the usability is developed so that the artificial leg could be used for football goalkeeper training. The possibility of using machine vision is investigated in order to read the position and movements of the goalkeeper for automatic control. Manual control of the device is executed by a game console controller.

2. METHODS

2.1 Original setup

The structure is based on steel beams and pipes which are attached together with bolted joints. All movements are implemented by pneumatic actuators. The kicking action was performed with 40 mm diameter fluidic muscle and ankle angle was adjusted with 20 mm diameter fluidic muscle. The leg was returned to the starting position after kicking with springs. A linear actuator was used to aim the kick horizontally. The ankle muscle and the linear actuator were controlled by 5/3 valves and the kicking muscle was controlled by a proportional valve. The structure is presented in Figure 2. [[5]]

The position of the linear actuator was measured with a linear position sensor and the angle of the ankle was measured indirectly with a pressure sensor. A large pneumatic cylinder was used as an air reservoir. The control system was implemented with a microcontroller and a computer. [[5]]

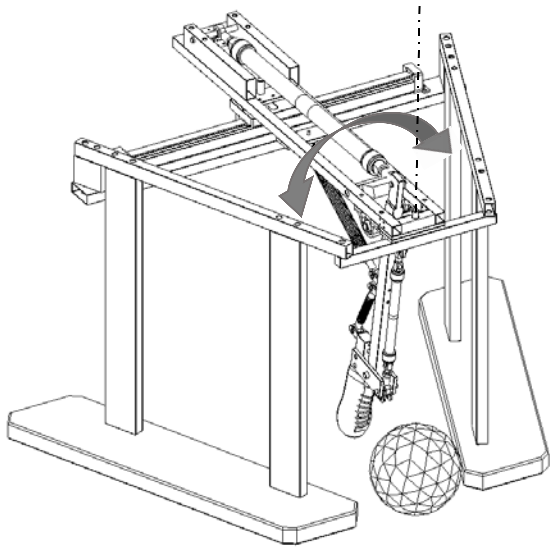

Fig. 2. Mechanical structure of the original setup [[5]]

2.2 Mechanical development

The main functional element of the device is the 40 mm fluidic muscle connected to hip and the 20 mm fluidic muscle connected to knee. These two muscles rotate the leg around these joints. Two completely new legs were constructed. The first was similar to the previous leg, except the ankle joint located higher (Fig. 3). With this procedure the ankle joint was transformed into a knee joint and the 20 mm muscle could be inflated during the kick to gain more velocity to the lower part of the leg. The second leg is simply a straight aluminium pipe (Fig. 3). This eliminates the elastic behaviour of the fluidic muscle located in the leg section. Both legs were tested with different amounts of weight added to them. The connection point of the hip joint muscle was also moved further away from the pivot point of the leg to examine the changes in the muscle's force output.

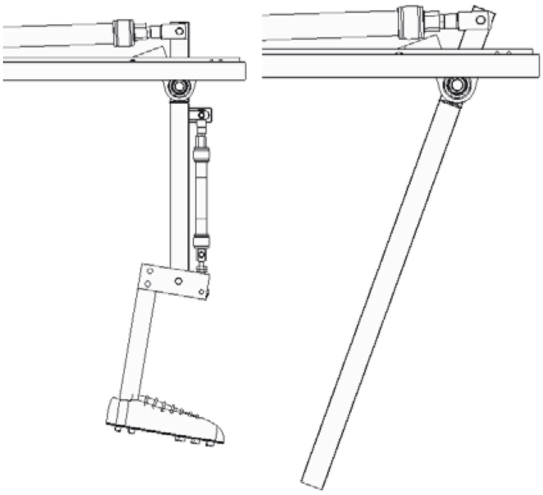

Fig. 3. New leg structures presented, a leg with a knee on the left and a straight leg on the right.

The vertical aiming mechanism was also changed from using the 20 mm fluidic muscle to rotate ankle to a stepper motor operated system that adjusts the ball position before the kick. The mechanism is located in the front section of the device as can be seen in Figure 4, which presents the final mechanical construction.

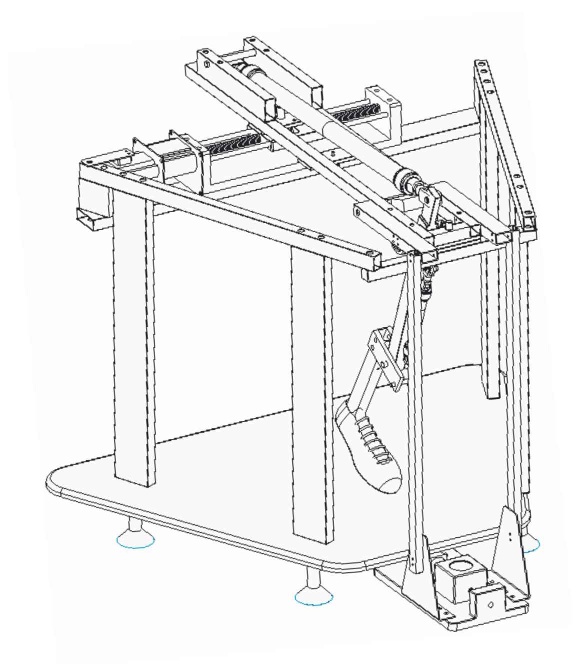

Fig. 4. The final mechanical construction.

2.3 Pneumatic development

The main advancement to the pneumatic system was replacing the proportional valve controlling hip joint muscle with a large on/off-valve to decrease the pressure drop during the kick. The deflation of the muscle was controlled with a smaller on/off-valve. Same type of setup was also constructed for knee joint muscle to ensure its sufficient air supply. Also, one pressure sensor was added mainly to measure the pressure of the hip joint muscle during the kick. The sensor was easy to move to different locations on the pneumatic system. The pneumatic system diagram is presented in Figure 5. The 40 mm hip joint muscle was replaced by a 20 mm fluidic muscle to increase the explosiveness of the kicking motion. The pneumatic linear actuator was replaced with mechanical linear drive and stepper motor for more accurate horizontal movement. The air tubing was also optimized by reducing the length and increasing the inner diameter of tubes.

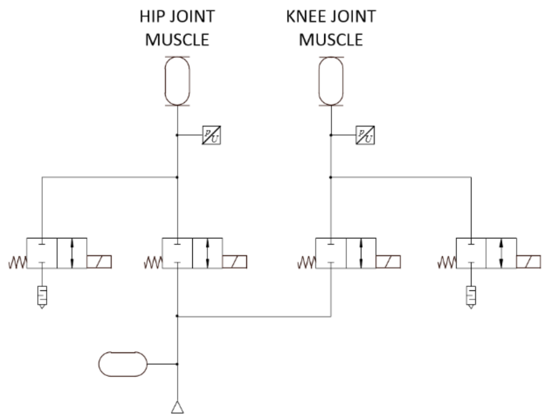

Fig. 5. Pneumatic system diagram.

2.4 Control system

The main control system is based on a microcontroller that drives the actuators and reads the information from the pressure and position sensors. The device can be controlled both automatically and manually. The automatic control system was implemented with machine vision including a laptop and a camera. The commands were sent to the microcontroller from a laptop via serial connection. The manual control was implemented with a video game console controller. The controller communicates directly with the microcontroller. The control system is presented in Fig. 6.

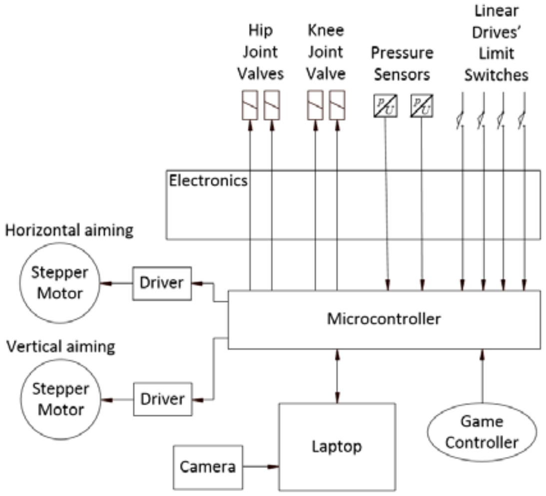

Fig. 6. Control system schematics.

2.5 Testing methods

The performance of the device was measured with a high speed camera. The speeds of the leg and the ball were calculated by using the camera's frame rate and a reference measuring line in the picture. Most of the measures were made with a 300 fps (frames per second) camera and final results were done with a 2000 fps camera to get more accurate results. The pressure measurements were made during the kick with two pressure sensors that sent the data via a microcontroller to a laptop. Results are averaged pressures of 10 separate kicks. The accuracy was measured by kicking the ball to the 1 x 1 m goal at the distance of 9 m and measuring the hitting coordinates.

3. RESULTS

The kicking speed was measured with various different modifications to the kicking device (Table 1). The ball position indicates the distance from the midpoint in the vertical aiming mechanism. The previous research [5] reached at best a speed of 51 km/h, when the ball was aimed as high as possible. The highest speed of 72 km/h in this research was reached with straight leg and additional mass attached, but this structure was further away from human-like leg. The final structure with a 40 mm hip joint muscle and a knee joint reached a speed of 68 km/h and although the target speed was not met, an improvement from the starting point was made.

Specifications	Ball velocity [km/h]	Foot velocity [km/h]
Ball position: 0 mm	68.2	48.8
Ball position: 0 mm	68	48.4
Ball position:+15 mm	66.5	45
Ball position: -10mm	67.8	48.9

Table 1. The kicking speed with different setups.

The pressure inside the fluidic muscle affects directly to the output force of the muscle. Therefore, the pressure during the kick movement has significant influence to the kicking speed. Although major improvement to the air flow was implemented, pressure isn't the full 7 bars during the kick (Fig. 7.).

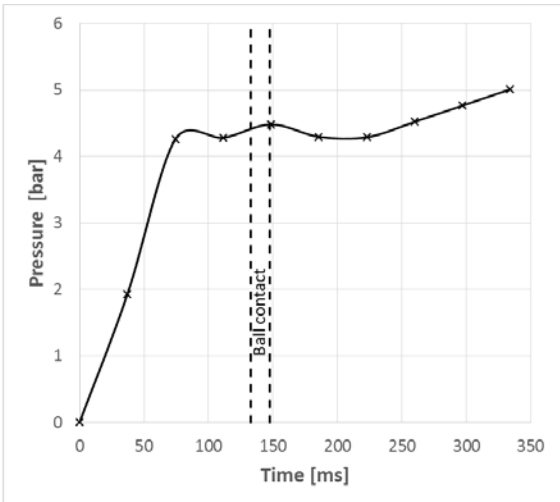

Fig. 7. The pressure in hip joint muscle during the kick.

The control system improved significantly the reliability and usability of the system. A game controller allows user to control the device without a computer attached. When the computer and a camera are connected, machine vision makes it possible for the goalkeeper to use the device alone for practising.

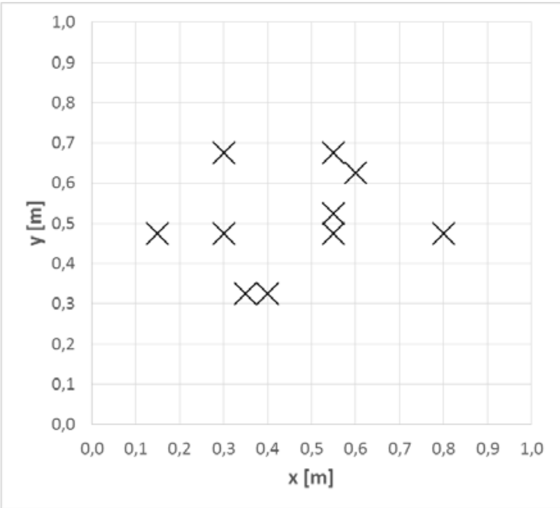

Fig. 8. The accuracy from the distance of 9 m.

The better accuracy was achieved with more accurate mechanical linear drive and a more accurate ball position holder. The goal of accuracy 1 x 1 m from a distance 9 m was achieved as seen in Figure 8. This is the maximum accuracy that the device can achieve when adjusted properly.

4. DISCUSSION

In this research, significant improvements were achieved to the football kicking device's properties. The performance, accuracy, reliability and usability of the device was improved. The kicking speed of the device was improved but the target speed was not fully achieved. The main reason for this was the limiting dynamic behaviour of the fluidic muscles in this structure. The accuracy achieved the goal of the research.

The dynamic behaviour of fluidic muscles makes it difficult to get high output force and rapid movement simultaneously. When the muscle contracts rapidly, the output force reduces. The main reason for this is the pressure drop due to the air flow into the muscle. The muscle with smaller diameter produces smaller static force, but requires smaller air flow and therefore it can even produce higher force in high speed movement. The output force also reduces as muscle contracts, so maximum force is available only in the beginning. These properties make it difficult to optimise the design to maximise the explosiveness of the movement. In this research, optimised parameters were muscle diameter, muscle length, the mass of the leg and the length of the muscle's contraction. The dynamic behaviour of fluidic muscles is also difficult to simulate, which makes the optimisation challenging. Manufacturers do not provide the parameters related to dynamic properties of fluidic muscles.

The idea of the device is to replicate the human dynamics in the football kicking. The structure of the moving leg is not an ideal for shooting football, because when imitating human movement compromises have to be made with performance. Better results could be achieved for example using two constantly rolling tyres where footballs would be fed between the tyres. This type of devices are implemented in training devices like Footbonaut and already used for example by Bundesliga team Borussia Dortmund in their training centre [6]. These types of equipment that simply launch the ball at high velocity are far simpler than mechanisms that actually kicks the ball making them more ideal for training use. When replicating the human leg, the fluidic muscles have many benefits to achieve explosive movements. However, they have as well limited dynamic behaviour. Imitating the complex human properties, such as explosiveness and accuracy in a compact size, is extremely difficult.

5. REFERENCES

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