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REAL-TIME MONITORING OF HUMAN BODY DURING HORSEBACK RIDING UTILIZING A HORSE SIMULATOR

Examiner(s): Professor Heikki Handroos
Dr. Hamid Roozbahani

ABSTRACT

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Real-Time Monitoring of Human Body During Horseback Riding Utilizing a Horse Simulator
Master’s thesis
2018
119 pages, 115 figures, 6 tables and 0 appendices

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Keywords: Horse simulator, horseback riding, electroencephalography, motion capture system, horseback riding therapy

In this work, real-time monitoring of human body during horseback riding utilizing a horse simulator was conducted. Horseback riding has been found to be an effective form of therapy in different musculoskeletal disorders. The general objective of this work is to build a proof-of-concept prototype of a novel horseback riding physiotherapeutic simulator system. For this purpose, couple measurement sessions were handled, and results are presented in the current paper. The idea is to monitor body and brain-behaviour of the professional rider and non-professional rider while riding a horse simulator, using inertial and optical motion capture systems and electroencephalography. Three types of experiment were made, two experiments represent body behaviour and one represents brain behaviour. The data was recorded, filtered if needed and analyzed.

ACKNOWLEDGEMENTS

The author would like to express her very great appreciation to her supervisors, Dr. Hamid Roozbahani and prof. Heikki Handroos for their patience guidance during the research, and for the environment provided to make this research possible. The author must also express her special thanks to Amin Hekmatmanesh for his huge contribution made with experiment, guidance and help with signal processing and neuroscience. The author acknowledges the help provided by Juha Koivisto with technical support in the laboratory. The author wishes to thank Asko Kilpelainen for his help with experiment and professional experience. The author also would like to thank all professional and non-professional riders, who participated in the experiment and helped with their big impact to the research. Finally, the author wishes to thank her parents for their support and encouragement throughout the study.

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Lappeenranta 04.8.2018

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1 INTRODUCTION

Implementing horseback riding as a form of therapy for a range of human disabilities has been spread worldwide recently. Therapy, based on benefits of horseback riding, improves posture, balance, gross motor function, energy expenditure, and health state (Whalen, C.N., Case-Smith, J., 2011), helps people with Cerebral Palsy. It has been estimated that in the Western world the prevalence of cerebral palsy is around 2 children in every 1000 live born (Annual Report of the European Agency for Safety and Health at work, 2002). Horseback riding therapy has been shown to improve posture (Bertoti, 1988) and gross motor function (Sterba, 2002) in children with cerebral palsy.

Scientifically proven that horseback riding is an effective form of therapy in different musculoskeletal disorders. For example, the beneficial impact has been noted in patients suffering from back pain and patients who have movement problems. Improvements in balance in patients suffering from multiple sclerosis (Cruickshank, T.M., Reyes, A.R., Ziman, M.R., 2015) and in rigidity and equilibrium in the early stages of Parkinson's have also been reported. Estimated 380,000 individuals suffering from multiple sclerosis in European countries. Costs of multiple sclerosis in euro (2005) total – 12.5 billion (direct costs, informal care and indirect costs) – could be reduced if accessible appropriate therapy became more widely available. Work-related low back disorders (including low back pain and low back injuries) are a significant and increasing problem. A report by the European Agency for Safety and Health at Work (2000) highlighted the extent of this problem, reporting that studies suggest that 60%-90% of people will suffer from low back disorders at some point in their life and at any one time 15%-42% of people are suffering. Since this initial report, a follow-up survey (2010) has resulted in confirmation of these findings in addition to identifying trends in the occurrence of work-related musculoskeletal disorders (Benda, W., McGibbon, N.H., Grant, K.L., 2003).

Learning basic principles how to ride a horse is a complex and time-consuming process. Riders require skills that can be obtained after several years of intensive training. In some cases, incorrect riding, as wrong position or poor posture, can cause serious problems not only for human's health but also for horse's one (Eskola, R., Handroos, H., 2009). Moreover, the unpredictable behaviour of the real horse is a big drawback, particularly, when it is concerned people with diseases and disabilities. Additionally, horses are expensive, and the maintenance costs are extremely high. In Finland, the maintenance costs range from 400-800 € per month excluding the veterinary expenses. The stables are normally located far from the city centres in the suburbs and countryside. This makes their access difficult for people with disabilities living in particular in large cities. Therefore, beneficial way of learning how to ride a horse correctly and safety is using a horseback riding simulator.

Horseback riding simulator which is studied in this work is a novel saddle motion hydraulic platform providing the capabilities that are required to mimic the real horse motion in all gaits, namely walk, trot and gallop. The data was collected from the real horse and implemented to the simulator. Simulator repeats three types of movement of the real horse (walk, trot and gallop) very close to the original movements as it was concluded after different people, including professional riders, tested the simulator. The general objective of this work is to build a proof-of-concept prototype of a novel horseback riding physiotherapeutic simulator system. For this purpose, couple measurement sessions were handled, and results are presented in the current paper. The idea is to monitor body and brain-behaviour of the professional rider and non-professional rider while riding a horse simulator. Three types of experiment were made, two experiments represent body behaviour and one represents brain behaviour.

1.1 Human Body During Horseback Riding

Biomechanics studies the functioning of the body in motion in terms of mechanical principles. Understanding the basics of biomechanics is especially important during the horseback riding lessons, in which two biomechanical systems, each with its own specific converge and effect on each other. To achieve the correct biomechanical dynamics from the collaboration of the two systems, it is necessary to understand not only the biomechanics of the horse but also the specifics of the biomechanics of the rider, which turns unbalanced movements into a harmonious whole. The knowledge about the biomechanics of the horse, which allows the horse to carry rider’s weight, are becoming more popular among riders. They are quite available for study, although sometimes there is not enough information. Nevertheless, the question of the rider’s biomechanics is raised much less frequently.

There are many controversial opinions about the principles of horseback riding. A lot of trainers and coaches tend to ignore the role of gymnastic education of the rider and knowledge how to use rider's body correctly, preferring to concentrate on the biomechanics of the horse. The main problem is that the right biomechanics of the horse, running under the rider, is the result of rider's correct biomechanics. The rider should pay as much attention to own body as to the horse's one. Some coaches say that the rider should be relaxed, while others believe that the rider should make an effort. In fact, good riding (riding with connection) is the ability to move in harmony with the horse. Meanwhile, certain joints need to be mobile and the muscles should be relaxed. Other muscles supposed to work to maintain posture and to direct the energy flow to the right direction. The body seems to develop in two opposite directions, and this makes riding such a unique discipline.

When a person starts to work on one part of the body to harmonize with the movements of the horse, which move postural and rebalance, the person opens the ideal representation of alternating functions, which is performed by the whole system, working in dynamics. One part works postural shown on figure 1 with blue arrows, that allows the neighbouring part to be coordinated, shown on figure 1 with green arrows and vice versa.

Figure 1. Force balance of the human while riding a horse

From the point of view of the impact on the horse, coordination allows connecting the rider to the movements of the horse, while postural retention rebalances the horse and directs its energy. It is noteworthy that the same pattern of balancing is present in the horse, which works in the body connection: a number of groups of muscles that support the skeleton of a horse, posture (have opposite direction) are balanced forward moving muscles. Together they form a ring connection that functions moving a pulse through the body of the horse. The rider's body also has connection ring, but its direction is opposite to the direction of the horse's connection ring. Both are connected as two gears in this mechanism.

Movements of the rider are usually defined by the horse. In this matter, the pelvis is considered as the "centre of movement" (Meyners, 2007) (or centre of the gravity) that determines the coordination between upper body and legs, shown on figure 2. Particularly the movement of the pelvis is playing the main role in controlling the horse as it connects the rider's body with the horse body (Panni, A.S., Tulli, A., 1994). Moreover, relevant muscles for horse riding (abdominal, back, hip, and thigh muscles) run from upper body and thighs to the pelvis (Munz, A., Eckardt, F., Heipertz-Hengst, C., Peham, C., Witte, 2013).

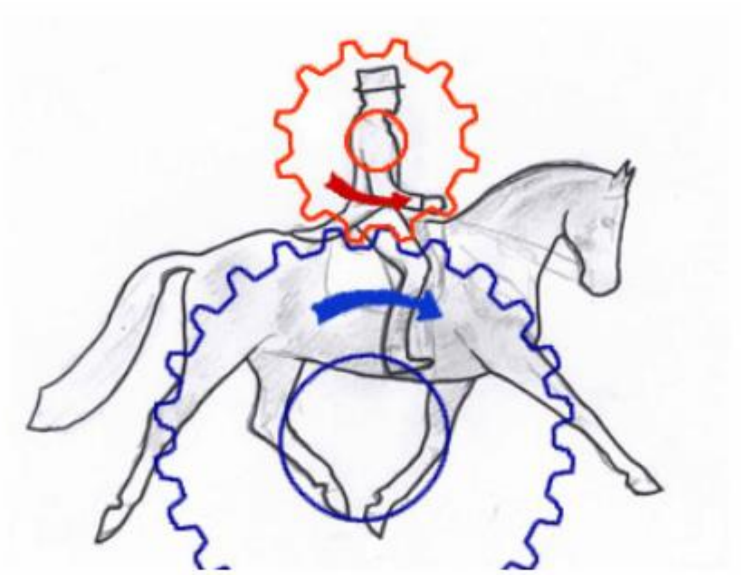


Figure 2. Force balance of the horse while moving

It is important to note that, both rider and the horse have a centre of the gravity (CoG), shown on figure 3. In the body of an average person, the centre of the gravity is located around the navel. Center of the gravity of different people depends on the body type and shape. It is believed that normal shaped women have shoulders narrower than hips and normal shaped men have hips narrower than shoulders. It means that the female centre of the gravity located lower and male centre of the gravity is located higher. Center of the gravity of the horse is located underneath the saddle.

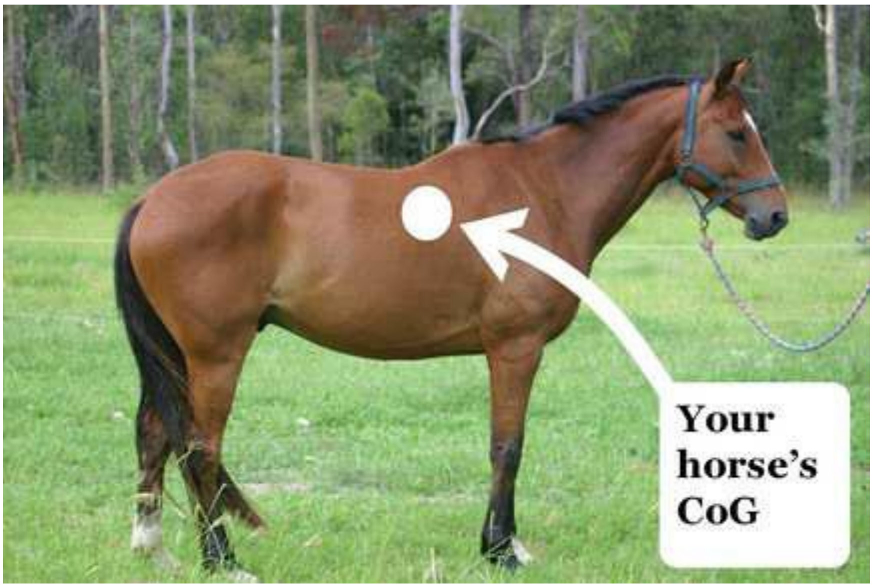


Figure 3. The centre of the gravity of the horse

Also, the centre of the gravity of the different kind of horses depends on the horse's shape and type. For instance, the centre of the gravity of the American Quarter Horse, which is usually lower in the wither (built downhill), is insignificantly forward of this point. Center of the gravity of Warmblood, which is usually higher in the wither (built uphill), is insignificantly further back. In some cases, training may modify horse's centre of the gravity and extend it a little bit, if training changes the balance of the horse. As a result, the horse that starts downhill and has a centre of the gravity forward finishes uphill. So, the centre of the gravity moves further back with profitable dressage training. While riding a horse it is obligatory to keep the centre of the gravity low as close to the horse's centre of the gravity as possible. Professional riders know how to locate their centre of gravity correctly, namely, closer to the lowest part of the saddle. Besides, learning to keep the weight as well low and to divide the weight correctly between the seat and the feet head to reach the centre of the gravity of the horse. It is very essential for a rider to perform all aforesaid actions to be secure, and to the horse, in its turn, to carry the rider. Nevertheless, it does not mean that the rider should grip the horse with legs, after all, it is a balance that keeps the rider on the horse, shown on figure 4.

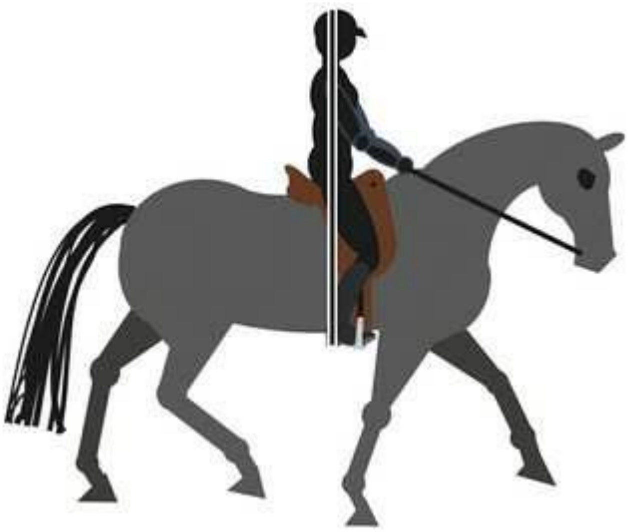


Figure 4. The correct position of the rider on the horse

However, the main question is still which group of muscles and body parts are mostly involved in horseback riding. Scientists highlight eight key muscles the lower part of the body involving in core stability. The core is more than just abdominals, it is an entire central unit. Muscles in core affect the spine, pelvis and ribcage stabilization. The pelvis is the most important body region involved in horseback riding. Wrong pelvis position of the rider can cause an unstable ribcage and shoulder girdle (Smith, 2016). It may affect not only the rider but also the horse. Often it is really hard to determine whether it is the rider's or horse's issue.

- Transverse Abdominus – helps to stabilize between hips, ribs, and pelvis;
- External oblique – helps to balance upon the horse;
- Psoas major – involves in flexing the hip and laterally rotates it. Also, it helps in flexing, extending and rotating the spine. This muscle controls the motion from front to back and manages the pelvis. Psoas has the power to restrict and release the rider's ability to absorb the movement of the horse;
- Iliacus – (similar to psoas major) has huge power in inhibiting or releasing the movement of the horse below the rider. This muscle together with psoas major is usually called iliopsoas or hip flexors;
- Piriformis - attaches to the front of the sacrum and to the top of the femur. This muscle with the help of psoas major provides rotation, flexion and extension of the hips and to keep balance on the horse;

- Gluteus maximus - helps to control the balance of hips from front to back, alongside the psoas. If these muscles are tight, it can inhibit the balance of the horse. If the muscle is faint, can cause the balance of the rider on the saddle. Gluteus maximus is a large powerful hip extensor;
- Quadratus lumborum - attaches to the bottom rib and to the lumbar vertebrae as well as the back of the pelvis (iliac crest). This muscle influences on moving, standing and riding;
- Gluteus Medius - rotates the hip in and out. This muscle helps the rider to stay balanced on the saddle.

Some people believe that the shape of the body somehow can affect riding skills. Luckily, body shape does not greatly affect on riding skills. The ideal body shape for riding is person with long legs and short upper body part (in order to keep the center of the gravity low), wide hips (for a wide base of support), flat chest (excess weight in the chest raises center of the gravity of the rider), and small head. As it was mentioned before, keeping the centre of the gravity low and closer to the horse centre of the gravity is very important. Conjectural and unrealistic female body shapes are shown on figure 5. On the left side, there is a unisex ideal body shape. On the right, the ideal body shape with short and heavy legs and long and plump body.

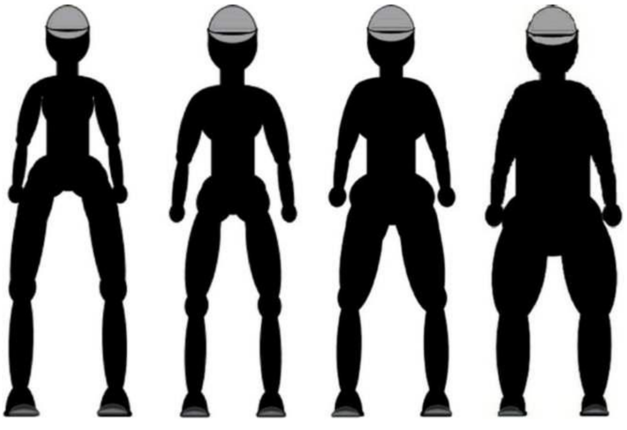


Figure 5. Ideal female body shape for riding

Almost the same situation is with the male ideal body shape, as shown on figure 6. From the left side, there is again unisex ideal body shape. Next there is the most desirable body shop for every man in everyday life, but unfortunately, it is not ideal for riding, the reason is that the top is heavy and the hips are narrow. Hips are surrounded by muscle around the top of the thighs and could not be narrow. Concerning pelvis, men have narrower pelvis than women.

The next body type is the best male shape for horseback riding. It does not heavy on upper part and legs are skinny, mostly, men have skinnier legs than women. Female's legs have a different shape because of the fat in the thighs and this may be considered as an advantage. The last body type is the ideal for a male with heavy and long upper body and short, skinny legs.

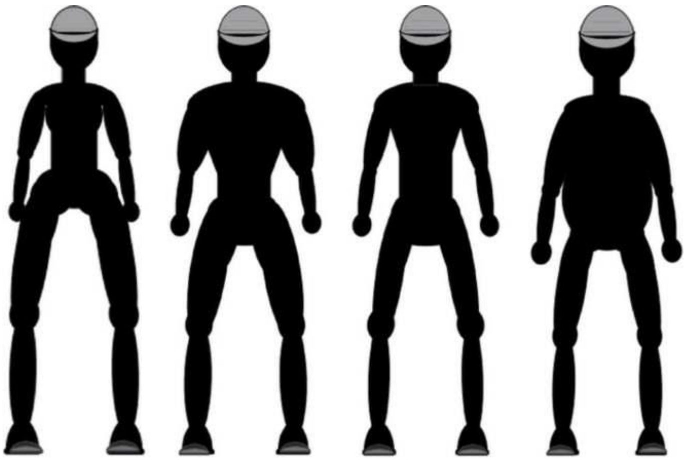


Figure 6. Ideal male body shape for riding

Good rider supposes to have a flexible body but strong and firm joints, not stiff or loose. Loose joints are weak and require special strengthening exercise to maintain the strength. People with stiff joints need to work on joints flexibility by stretching it both while riding the horse and in real life. Positions of the ankles while riding the horse are very important. Rider should know how to keep the correct position for the lower leg. Ankle's stiffness usually prevents riders to keep this position in natural way (Figure 7, position a). Keeping the correct position for the lower leg helps the rider to balance on the horse and how to control the horse (Figure 7, position b).

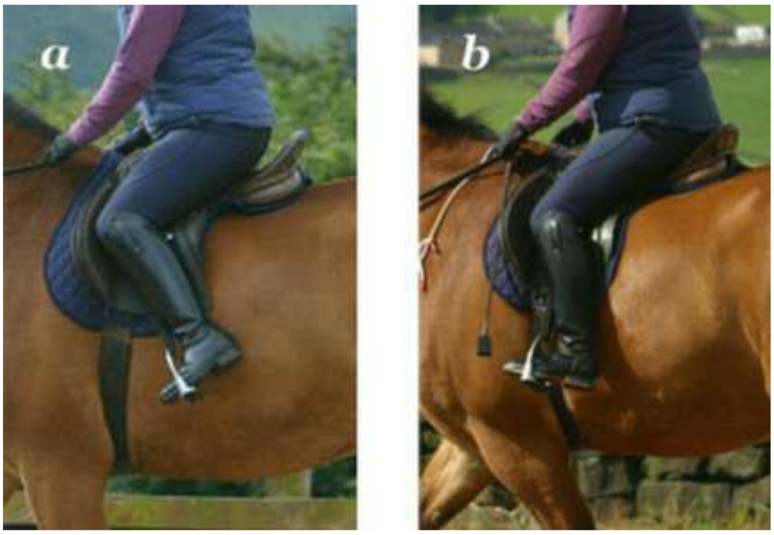


Figure 7. Positions of the ankles while riding the horse

1.2 Horseback Riding Effect on the Body of Disabled Person

While doing horseback riding therapy the person receives movements of the horse, what creates movement in the pelvis and torso that resemble human gait (Fleck, 1997). As a result, all the muscles and joints of the human body are involved and exercised, especially ones that are required for walking (Bertoti, 1988). There are two major effects of riding on people who deal with it. This is an emotional connection with animal and quite hard conditions of riding the horse, requiring the mobilization of physical and mental effort. The need for constant concentration in horse riding, self-organization, focusing. Also, the need to remember and plan the sequence of actions, both when riding and when caring for animal activates mental processes. The positive effect of horseback riding is based on a complex effect on the human body. Even with a calm step, the human body is forced to follow the movements of the horse, thus there is a range of passive movements in the joints and spine, and muscles work even without much effort on the part of the person. Treatment of patients with neurological symptoms, children with cerebral palsy by horseback riding is based on this effect (Benda, W., McGibbon, N.H., Grant, K.L., 2003). There is a huge influence on the emotional impact of communicating with a large, beautiful, and loyal animal on the human psyche.

From ancient times the humanity was known about the benefits of horseback riding. Ancient doctors believed that horseback riding strengthens the whole body, some of them, recommended treating diseases of the gastrointestinal tract by horseback riding. Doctors of subsequent generations found that walks in the saddle have a positive impact on the digestive functions of the person, on the circulatory system, nervous, respiratory and endocrine systems. Modern scientists believe that horseback riding is a great emotional shake-up and stress relief. When riding, the horse transmits to the person about 100 motor pulses in just one minute, which makes the human body constantly obey to the new movement, perceiving every new push and impulse. Load while riding a horse depends on the gait in which the horse is moving. For example, the lynx trot is equal to active walking of the person, while the gallop is equal to running on rugged terrain. During relaxed riding the person experiences significantly less impact on the joints and spine than walking or running, but at the same time, the person has to use almost all muscle groups to maintain balance. Therefore, horseback riding therapy is recommended for people of all ages. It can be prescribed to recover when only the smallest physical activity is permissible. Also, it can be recommended for diseases caused by a sedentary lifestyle.

Horseback riding helps to create a strong muscular corset around the spine, due to this, blood circulation, and the metabolism in the intervertebral discs are normalized. All muscle groups of the rider simultaneously included in the work. Moreover, this happens at the reflex level, because the rider instinctively tries to keep the balance, not to fall off the horse, and thus encourages the active work of all major muscle groups. The need of constantly maintaining the balance forces trains vestibular apparatus hardly, which obliges to constantly keep the back "flat", eliminating from the curve of posture and slouch. Such exercises help to massage the internal organs, all the muscles are constantly relaxed and contract, while in an unstable position. It is difficult to achieve a similar effect in any other sports activities. The constant movement of the horse such as "forward-backwards", "left-right", "up-down" well tone muscles well, improve shape, as well as influence positively to the work of all internal organs.

There is a partial list of diseases for which therapeutic riding is effective. First of all, it is a large group of orthopaedic diseases: complete and partial paralysis of hands, feet, violations of movements coordination, spinal curvature, posture defects, arthrosis of joints, osteochondrosis, scoliosis, kyphosis, and diseases of the musculoskeletal system, the most common one it is a lower back pain. Bending and twisting are the mobilities for everyday motions provided by the low back, or lumbar spine, as well as supporting the weight of the upper body. Group of muscles that are located in the low back in charge of supporting the spinal column, moreover, for flexing and rotating the hips during walking. Nerves in the low back supply sensation and power the muscles in the pelvis, legs, and feet (Peloza, 2017).

Low back pain can cause a wide range of symptoms to start from mild and annoying to hard and weakening. Pain may occur suddenly, slowly, coming and going sometimes or gradually get worse every day. Symptoms of lower back pain are usually described by the type of onset and duration: acute pain (suddenly comes and lasts for a few days or weeks), subacute low back pain (prolonged, mechanical in nature, lasting between 6 weeks and 3 months), chronic back pain (lasts over 3 months, hard feeling of pain, does not respond for initial treatments) (Deardorff, 2017). Having described range of lower back symptoms there are two common types to categorize low back pain: mechanical pain and radicular pain. The identified trend towards static work postures and the risks associated with prolonged standing and sitting that were noted to be both significant and as yet underestimated are likely to result in further increases in the prevalence of low back disorders.

In therapy, horseback riding recommends in the treatment of coronary heart disease, metabolic disorders, bronchial asthma, vegetative-vascular dystonia, functional bowel disease, rectal diseases, etc. At the same time, there are no increased loads on the heart muscle. Therefore, hippotherapy, shown on figure 8, is excellent even for hypertension and cores, of course, with the observance of basic safety regulations. In surgery, therapeutic riding is successfully used to restore movement ability after accidents and heavy operations. Riding is very useful for those people who undergo rehabilitation after a stroke or heart attack. Beneficial and decisive in this situation is the fact that the pulse of the rider during horseback riding can reach 170 beats per minute, blood circulation is increased in 5 or even 10 times.

Figure 8. Horseback riding therapy session

In neurological and psychiatric practice riding is indicated as a treatment of peripheral and central nervous system pathologies to eliminate the effects of stroke, epilepsy, autism, some forms of schizophrenia, oligophrenia, down syndrome, as well as multiple sclerosis, various depression, neuroses, mental retardation, alcoholism, drug addiction, social adaptation, and, especially cerebral palsy. Cerebral palsy is a term that combines a group of chronic non-progressive symptoms of motor disorders secondary to lesions or abnormalities of the brain that occur in the perinatal period (Anttila, H., Malmivaara, A., Kunz, R., Mäkelä, M., 2006).

Usually, cerebral palsy appears in early childhood or even earlier, during pregnancy, and related to brain injury or brain development. Symptoms include poor coordination, stiff and weak muscles, tremor. Cerebral palsy can be caused by premature birth; loss of blood, oxygen, any other nutrients before or during a birth; serious head injury; infection, such as meningitis, that can affect the brain; genetic problems passed from parent to child (McAdams, R.M., Juul, S.E., 2011).

In gynaecology, horse riding also has a great effect in many chronic female diseases, by improving the blood supply to the pelvic organs and strengthening the abdominal muscles and perineum. Experts also note the fact that the horse's body temperature is 1.5 – 2 degrees higher than the human body temperature (even more when the animal moves calmly), that with direct contact produces warming of all pelvic organs, muscles and feet joints, improves blood circulation. There are a number of medical contraindications to riding. In some cases, a specific training load may be excessive for the body of the sick person. The main contraindications are experienced stroke and heart attack, all acute diseases of the internal organs, balance disorder, acute thrombophlebitis, vein thrombosis, and trophic disorders of the lower limbs. Horse riding is also contraindicated in acute inflammation of the kidneys, bladder, prostate and some gynaecological diseases. Before starting practice horseback riding therapy, it is obligatory to have a consultation with a doctor.

1.3 Literature Review

The positive effect of horseback riding has been scientifically proven many years ago, but scientists still study this topic by exploring new methods to implement it in real life. Implementing horseback riding as a therapy mostly used for elder people and children with some health issues. The most common musculoskeletal disease, which can be healed by horseback riding therapy sessions is low back pain. Asymmetry leads to the chronic back pain as both human and horse bodies are symmetrical (Nadler, S., Malanga, G., DePrince, M., Stitik, T., & Feinberg, J., 2000). Using modern motion capture systems give a better understanding of how human’s body behaves while riding the horse, implementing horseback riding simulators for people’s treatment significantly simplifies researches and makes therapy more affordable for the society.

There were numerous studies investigating posture and asymmetry of the rider during horseback riding in the literature (Peham, C., Licka, T., Schobesberger, H., Meschan, E., 2004), (De Cocq, P., Clayton, H.M., Terada, K., Muller, M., Van Leeuwen, J.L., 2009), (Symes, D., Ellis, R., 2009), (De Cocq, P., Duncker, A.M., Clayton, H.M., 2010). According to (Gandy, E.A., Bondi, A., Hogg, R., Pigott, T.M.C., 2014) inertial sensing technology has used an indicator of asymmetry for external rotation of left and right hip. The experiment took place in the riding area, riders were asked to ride on a straight runaway. The experiment accounted for twelve horses and riders. Riders were equipped with Xsens MVN motion capture lyrca suit with seventeen embedded inertial measurement unit sensors. Data was collected wirelessly via Bluetooth by the software MVN Studio, which allows observing, record and export in three-dimensions, provided by the company. There were five different scenarios of horse's movement for data capturing: trot rising (left rein straight line), trot rising (right rein straight line), trot rising (left rein circle), trot rising (right rein circle) and halt. The aim of the experiment was to measure the external rotation of the hip along the femur's longitudinal axis. Larger angle indicates greater external rotation, the difference between left and right hip indicates the asymmetry. Moving through the rise and sit rider's phases means the range of external rotation angle for the hip, with values ranging from 1^{o} to 27^{o} and 83% showed greater external rotation of the right hip. The asymmetry changed when rider moved from sitting to rising position of the trot stride cycle. The asymmetry of the horse, which may be caused by one side stiffness, can lead to shortening the step. All the movements that a rider receives from the horse are absorbed mostly by the lower region of the body such as the pelvis and hip joints. If the rider loss any mobility at the pelvic region, then all force from horse's movements will transfer to the lumbopelvic region.

Following (Hobbs, J.S., Baxter, J., Broom, L., Rossell, L., Sinclair, J., Clayton, H.M., 2014) work it was concluded that rider asymmetry is recognized as a negative feature. Asymmetry can be obtained from numerous parts of the human's body. The aim of the work was to discover the symmetry of posture, flexibility, and strength in a large group of riders and understand if there are any special habits in riding. 134 riders participated in the experiment, including 123 males, 2 females; 127 riders were right handed, 5 left handed, and 2 were able to manage the horse with left and right hand, due to the fact that the whole group doesn't represent normal population in relation to handedness (Annett, 1967) only right-handed rider's data was used. Infrared motion capture system, consisting of cameras and retro-reflective markers, was used in the experiment to collect the data. Calibration of the system was carried with respect to the horizontal axes in order to place the horse model is able to place along the axe. Markers were placed to the left and right shoulder joints, hip joints, to the back along the spine, greater trochanter, which is located one cm lower than the head and the upper back area in a group of four markers.

The first measure was connected with the standing position of the riders to capture the anatomical position, then sitting position of the rider on the dressage saddle of the horse model was captured. The aim of the experiment was to measure the trunk flexibility. In addition, a wooden stick was placed across the shoulders. It was made to reduce the motion of the shoulder girdle. For range of motion capturing the riders were asked to do slow left and right rotation movements as there was no real horse or at least horse simulator took place in the experiment (Hobbs, J.S., Baxter, J., Broom, L., Rossell, L., Sinclair, J., Clayton, H.M., 2014). After every cycle, the riders were asked to return to the initial position. Three cycles of each motion were captured randomly. The main factors of the study were years of riding experience and competition experience. Following parameters were measured: leg length, grip strength, height of the acromion processes and iliac crests during standing and seated posture, lateral bending of the motion's range and rotation of the motion's range (Hobbs, J.S., Baxter, J., Broom, L., Rossell, L., Sinclair, J., Clayton, H.M., 2014). The wide of asymmetry was devived into two groups by shoulder joints location for a group that took part in the competition and by hip orientation for a group with riding experience. Significant functional asymmetry was found in the hip region of the motion's range for a group with years of riding experience in comparison with competition level. The requirements that are presented for professional dressage riders, which competing at a higher level are able to cause a chance of asymmetry and possibility of a chronic back pain development rather than improving the symmetry of the professional rider.

The main aim of the work (Munz, A., Eckardt, F., Heipertz-Hengst, C., Peham, C., Witte, 2013) was to discover the possibilities and limitations of inertial sensors to estimate the motion of the rider's pelvis in walk, trot, and canter, especially with opportunity to repeat the experiment as based on authors statement there is no suitable sensor-based method for rider's pelvis analysis. Two professional female riders participated in the experiment. Riders have riding experience for over 30 years, they rode for three-six hours per week. Riders did three cycles in an outdoor riding area with 15 minutes break between each cycle. Each cycle consisted of following gaits: two circles of walking, three circles of rising trot, three circles of sitting trot and three circles of left-lead canter. For data collecting, two orientation trackers (6 degrees of freedom) by Xsens Technologies were synchronized with the three-dimensional accelerometer and camcorder. As the system has two inertial sensors and accelerometer, which was placed on the left cannon bone of the front limb, the first was fixed to the rider's pelvis, second was located centrally on the horse's sternum to the saddle girth (Munz, A., Eckardt, F., Heipertz-Hengst, C., Peham, C., Witte, 2013). First sensor represents how the pelvis is linked to the horse's trunk, second sensor measures the movement of the horse's trunk, with the help of accelerometer, the beginning and the end of each horse's step was determined (Munz, A., Eckardt, F., Heipertz-Hengst, C., Peham, C., Witte, 2013). In this paper three cycles, with respect to the gait type, were analyzed, counting overall between 98 and 174 steps for each rider and between 6 and 11 steps for every straight line of a circle.

In the field of interested was to capture the position of the rider's pelvis and the horse's sternum while riding. They are represented by two angles, called anterior-posterior and lateral. Anterior-posterior angle represents the rotation of the mediolateral axis for the pelvis and sternum, lateral angle corresponds to the rotation about the sagittal axis in case of the pelvis and about craniocaudal axis in case of the trunk (Munz, A., Eckardt, F., Heipertz-Hengst, C., Peham, C., Witte, 2013). The movements of the rider were characterized as anterior-posterior and lateral angles for the pelvis's range of motion.
The difference between the highest and lowest value in one complete step was mentioned as the range of motion. It was concluded that craniocaudally and sagittal axis are not so important, because pelvis and sternum rotate mostly about a mediolateral axis. However, one of the sensors was attached to the movable part (trunk of the horse, not a rigid body), it caused some inaccuracy in measurements. The values of coefficient of multiple correlations from two riders allow repeating the similar experiment by proposed method with changing the location of the sensor on the sternum.

The aim of the (Eckardt, F., Witte, K., 2017) work was to approach and describe the way of horse-rider interaction based on inertial measurement units during diverse levels of horse movement such as walk, sitting trot and canter. Horse-rider interaction was characterized by the time lag of mutual correlation between particular parameters, for example: if the time lag is small, the interaction between the horse and rider will be better. Ten professional riders (eight females and two males) and ten (seven females and three males from riding school) non-professional riders participated in the experiment. The participants used their own horses and equipment as dressage saddles and bits. For data collecting the Xsens Technologies MVN suit and sensors were used. The MNV represents movements of the riders, the MTx sensors represent the movements of the horses, and the three-dimensional wireless accelerometer was used to identify the beginning and the end of the step. The MTx and accelerometer placed on the horse. The accelerometer was placed on the left cannon bone of the front limb and the inertial sensor was fixed centrally on the horse's sternum to the saddle girth as this location approximately represents the horse's center of the gravity (Munz, A., Eckardt, F., Heipertz-Hengst, C., Peham, C., Witte, 2013). One experiment cycle consists of riding straight on 30-meter outdoor sand track four times: in the walk, sitting trot and left-lead canter with a fix working speed. The MVN data was received in relative angles and transferred to Euler angles, smoothed after by filtering. As a complete step, it was considered the time between left front limb two ground contacts.

For the analyzation data was separated into strides (101 samples each stride) using Matlab code and the kinematics of horse and rider was calculated. Analyzing the relative angles and vertical acceleration was made for segments of the rider and trunk of the horse. The relative angles of the riders and the horses were described by rotations about two axes: over the mediolateral axis (roll) and over the sagittal axis (pitch). The time lag is the maximum and minimum of cross-correlation. The time lag was analyzed between trunk of the horse in contrast with pelvis of the rider (roll), trunk of the horse in comparison with pelvis of the rider (pitch), trunk of the horse in relation to pelvis of the rider (vertical acceleration), trunk of the horse in contrast with pelvis of the rider (roll), trunk of the horse in comparison with pelvis of the rider (pitch), and trunk of the horse in relation to pelvis of the rider (vertical acceleration). With considering that the segments of the rider rotate in the opposite direction as the trunk of the horse, the minimum time delay was identified (Eckardt, F., Witte, K., 2017). While comparing professional and non-professional riders it was noted that the velocity of the professional riders group was higher in all three studied gaits. Besides, the results of cross-correlation analysis show the better interaction of the horse and rider in roll (sagittal plane) than in pitch (frontal plane), independently of the studied skill levels and gaits. Multivariate analysis of different time delays was made. The result show statistically significant differences for vertical acceleration between pelvis of the rider and trunk of the horse and the vertical acceleration between rider and rider's pelvis (Eckardt, F., Witte, K., 2017). Nevertheless, no considerable distinctions between the two studied experience levels after multivariate analysis were revealed. For estimation, the relations between the factors of gait and experience level cross-correlation method of results analyzing was applied. The factor of the experience level shows only the statistical interaction between the bonding the horse's trunk and rider's pelvis, presented paper clearly illustrates the potential of a modern method to define and describe the interaction between horse and rider (Eckardt, F., Witte, K., 2017).

As stated by (Munz, A., Eckardt, F., Witte, K., 2014) rider's pelvis and the horse cooperate among themselves physically. Pelvis of the rider plays a key role in horse riding. This article is about how riding skills effect on the interaction between human's pelvis and the horse. Ten professional riders (eight females and two males) and ten (nine females and one male) non-professional riders participated in the experiment. For data collecting the Xsens Technologies MVN suit and sensors were used. The MNV represents movements of the riders, the MTx sensors represent the movements of the horses, and the three-dimensional wireless accelerometer was used to identify the beginning and the end of the step. The first inertial sensor was attached spinal to the pelvis of the rider. The second inertial sensor was placed in the centre of the saddle under the sternum of the horse. The accelerometer was fixed on the left cannon bone of the front limb in order to identify one full step, according to the method offered in the study (Starke, S.D., Witte, T.H., May, S.A., Pfau, T., 2012) and (Schamhardt, H.C., Merkens, H.W., 1994). One experiment cycle consists of riding straight on 30-meter outdoor sand riding hall four times: in the walk, sitting trot and right-lead canter with a fix working speed. Before the experiment started, the orientation of the pelvis of the rider was captured in the natural standing pose. The position of the rider's pelvis and the horse's sternum are represented by two axes, called anterior-posterior and lateral, for the pelvis and the sternum, anterior-posterior corresponds to a rotation about the mediolateral axis, lateral was defined as the rotation about the sagittal axis of the pelvis and as a rotation about the craniocaudal axis of the trunk (Munz, A., Eckardt, F., Witte, K., 2014).

The signal from the accelerometer, which was fixed at the cannon bone was zero-phase-shift low-pass filtered. Complete stride was set as the time between left front limb's two ground contacts. The orientation of the rider's pelvis was represented with respect to the natural upright standing posture, the orientation of the horse's trunk was shown with respect to the pause (Johnston, C., Holm, K., Faber, M., Erichsen, C., Eksell, P., Drevemo, S., 2002) using following procedure: the data was separated into strides as 101 samples each stride, each of the angle's time series was grouped in 30 strides for each subject in each gait for determining differences in groups described by (Faber, G.S., Kingma, I., Bruijn, S.M., 2009). The waveform parameters were obtained from the following cycles: range of motion, maximum, and minimum for analyzation. The time lag between the maximum cross-correlations among trunk of the horse in contrast with pelvis of the rider was used to quantify the phase shift between groups (Munz, A., Eckardt, F., Witte, K., 2014). Considerable features were discovered in anterior-posterior rotations in all gaits, nevertheless, not in rotations along lateral axe. Maximum, minimum and range of motions values of rider's pelvis vary widely among subjects of study in groups of professional and non-professional riders. Moreover, anterior-posterior rotation of the pelvis was defined in canter as the greatest displacement, after in trot and walk. It was observed, that horse's trunk mostly rotated during canter, walk and trot, respectively, from higher to lower rotation. Investigating lateral rotation during all gaits the same rotation was noticed. In addition, higher anterior-posterior angles of horse's trunk were monitored during all gaits. There were not noted any statistical differences among the investigated groups. Although, in all gaits, professional riders keep pelvis closer to the middle of the saddle while non-professional riders keep pelvis more to the right side of the saddle. The comparison of the professional and non-professional riders reflects that the seat of the professional riders differs by the more forward-tilted pelvis.

In a manner corresponding to (Clayton, H.M., Kaiser, L.J., de Pue, B., Kaiser, L., 2011) the study is related to comparing the anterior-posterior and medial-lateral range of motion and velocity of the center of the pressure on the horse's back between riders without disabilities and riders with cerebral palsy. There were two groups of riders divided by four people (eight riders in general) without disabilities and cerebral palsy, respectively. The participants rode the same horse in the saddle without any special supporting structures. The participants had experience of riding the horse as a form of therapy before the experiment. For the one experimental cycle, the rider rode at a walk for four minutes in the indoor arena, the experiment took two days. To track movements of the rider centre of the pressure a special electronic pressure mat was used. The measurement is based on the force distribution under the saddle. Special pressure mat with 256 individual sensors was used. The mat was calibrated every time at the beginning of the experiment. The pressure mat was placed on the back of the horse beneath the saddle. For every participant, ten-second pressure recording was made. The rider's center of the pressure was tracked, and the maximal and minimal coordinates of the data points in the anterior-posterior and medial-lateral directions were used to measure the ranges of motion of the center of the pressure (Clayton, H.M., Kaiser, L.J., de Pue, B., Kaiser, L., 2011). Overall there were three cycles for each rider for which velocity was recorded and calculated using the following method. The method represents the division of data points by time integration. The centre of the pressure displacement was considered. For every cycle, the velocity was averaged and calculated to determine the values in the studied direction. Nonparametric statistics were used due to the small step size.

The results after calculation were compared using the Mann-Whitney test. Greater results for a range of motion and velocity of the centre of the pressure in anterior-posterior, medial-lateral and medial-lateral directions, respectively, were obtained in the group of riders with cerebral palsy. As an exception, it was considered that greater range of motion and velocity of the centre of the pressure in an anterior-posterior direction referred to the rider with cerebral palsy (Clayton, H.M., Kaiser, L.J., de Pue, B., Kaiser, L., 2011). Also, a group of riders with cerebral palsy show a direct distribution of the pressure patterns. Almost the same pressure motion patterns were noted for both group of riders but with greater deviation in the group of riders with cerebral palsy.

The study of (Kim, S.G., Lee, J.H., 2015) is based on the effect of using horse riding simulator to monitor trunk muscle activation and balance on elder people. Additionally, the therapeutic advantages of horseback riding were investigated. Thirty elder persons from a medical care hospital participated in the experiment. They were randomly divided into two groups: experimental and control. The participants were selected according to the following criteria: over 65 years old, able to walk independently over a ten-meter distance, no experience of falling, without having any diseases that can influence the result or with vision, auditory sense, vestibular apparatus, cognition problems. Also, all participants were obligated to take part in the Mini-Mental State Examination (or Folstein test) and score more than 24 points. An examination is a 30-point form that is widely used in clinical research to evaluate cognitive impairment (Folstein, 2001). Horse riding simulator (Hongjin, Model H-702, Anseong-si, Korea) was used for the experiment. The experiment group was asked to utilize the simulator for twenty minutes, five times a week, for eight weeks. People who participated in the experiment had five minutes warm up before the experiment begins, along with the conventional therapy. The horseback riding simulator is designed to repeat three-dimensional movements of the real horse such as anterior and posterior, right and left, upward and downward for supplying therapeutic effect of riding exercise. The participants were instructed to keep the upright balance during the experiment. Simulation speed was controlled based on the comfort level of every individual.

Five core muscles, which are important in trunk stability, such as rectus abdominis, erector spinae, quadratus lumborum, external oblique, and gluteus medius were studied for monitoring muscle activation (Criswell, 2004). The data was collected as an EMG signal, the space between recording electrodes was two centimetres. Later, the potential difference between two electrodes was compared. The electrodes were attached in parallel to the muscle fibres. Recording the maximum range at each direction limit of stability was measured. After the experiment is completed, limits of stability and muscle activation significantly increased in the group that participated in horse riding simulation therapy cycle. In the control group, the muscle activation of quadratus lumborum, external oblique, and gluteus medius extremely decreased, without having any difference in other muscles. Consequently, based on the result of muscle activation and balance were improved, it is clear that horse riding simulator exercise is considered effective.

Energy expenditure, enjoyment, and task difficulty were compared for exercise with a horse-riding simulator and real horseback riding and analyzed according to riding speed and participant age (Kim, M.J., Kim, T.Y., Choi, Y., Oh, S., Kim, K., Yoon, B.C., 2016). Most of the studies related to real horseback riding or studies using horseback riding simulator are concerned on children with cerebral palsy, autism, and Downs syndrome. Rarely, studies involving adults and mostly focused on multiple sclerosis and stroke, but not a healthy population. Thirty-four young adults and twenty-six older adults participated in the experiment. The participants were randomly derived in two groups according to the riding type: for the horseback riding simulator and for the real horseback riding. The first group for horseback riding simulator numbered eighteen young adults and seventeen older adults. The second group for real horseback riding numbered sixteen young adults and nine older adults. The participants were selected according to the following criteria: healthy person, having no experience with horse riding simulator or real horseback riding, without having any neuromuscular impairments, chronic back pain, cardiovascular, psychological disease, surgeries or traumas within the previous 3 months, and without drinking alcohol within 24 h or smoking within 3 h of the experiment. Following gaits: walk, slow trot, and fast trot was chosen. The experiment time was 61 minutes, consisted of 15 minutes for each gait (45 minutes in total) and 8 minutes rest between gaits (16 minutes in total). Horseback riding simulator (FORTIS-102, Daewon FORTIS, South Korea) was used for the experiment.

Enjoyment and received task challenge were measured using a visual analog scale. Furthermore, the oxygen uptake and metabolic equivalents according to different speeds and participant ages were measured. The participants agreed that the perceived task was either difficult or enjoyable. Pulmonary gas exchange and respiratory gas were continuously measured at all 3 gaits using a portable gas analysis system (K4b2 COSMED, Rome, Italy) to measure oxygen uptake and metabolic equivalents.

In case of an emergency, the participants were wearing a harness and heart rate monitor (RS 400, POLAR, USA). The participants reported a great experience, pleasure and enjoyment after the experiment with a real horse, none of the following factors was noted task difficulty, oxygen uptake and metabolic equivalents. With increasing the speed, the gait pattern revealed faster and more complicated coordination. Listed parameters were enhanced. The older adults represented greater enjoyment and less task difficulty than young adults for both horseback riding simulator and real horseback riding cycle (Kim, M.J., Kim, T.Y., Choi, Y., Oh, S., Kim, K., Yoon, B.C., 2016). Horseback riding simulators may replace and can be more suitable than real horseback riding for elder people due to security reasons with low-intensity exercise.

As reported by (Silva e Borges, M.B., Werneck, M.J., 2011) to maintain the postural control is an essential reason in performing daily activities and therapeutic effects of the horseback riding simulator in children with cerebral palsy are carried in this study. The participants were forty children with cerebral palsy, they were randomly divided into two groups. The first group of twenty children, including eight boys and twelve girls in the age range from three to twenty years old, was riding the horseback simulator. The second group of twenty children, including nine boys and eleven girls in the age range from three to ten years old, was experiencing the regular physical therapy. The postural control of the body of every child was evaluated by the body oscillation, which was recorded before and after the experiment. The assessment of the anterior-posterior and medial-lateral body oscillation was performed by the recording of the maximum displacement. The platform was located on a stand for the seated child accommodation. The wooden blocks were used for feet supporting and keeping the child in the comfort in a relaxing position.

The data was recorded for one minute, while the child, sitting on the platform, was asked to cross his arms hugging himself and to move the body forward and backwards, and from left to the right. The children from the first group underwent twelve sessions of the physical therapy based on NeuroDevelopmental Treatment in two weeks for 40 minutes each, with the accent on a specific method for trunk control. The children from the second group underwent twelve therapy sessions in two weeks for 40 minutes each using the horseback riding simulator (Joba, Matsushita Electric Works, Japan). As a result, both displacements in anterior-posterior and medial-lateral were higher in the second group, using the horseback riding simulator, comparing with the first group finishing the regular physical therapy. The individual pre-test measurements received in the anterior-posterior displacement in both groups and the average of the post-test results were significantly higher in the second group using the simulator than the average results obtained in the first group. The same outcomes were achieved in the medial-lateral displacement for the group using the horseback riding simulator.

From a fundamental viewpoint, the interaction between horse and the rider may be considered as a coherent brain activity. It is a neurocommunication process that defines not only mood, feeling, and behaviour of the rider, but also of the horse. A better understanding of the processes that occur in the brain can help the rider in the dressage carrier. The most important part of the brain is the prefrontal cortex. This part of the brain controls all the feelings, emotions and behaviour (Arenander, 2015). The cortex is located right behind the forehead. It takes all the information from the senses, motor activity, feelings, and organizes thoughts and actions to achieve the goals. The horse also has a cortex and it works exactly like a human's one. The dopamine is a small neurotransmitter molecule considered as a chemical signal that passes information from one neuron to another (Arenander, 2015). The dopamine is responsible for the maximum and minimum of the feeling level, behaviour, self-confidence, motivation, and relationships with the partner. In the human's brain, there are about 1000 billion cells and a huge number of neurotransmitters are constantly exchanging between cells. Again, the same attitude applies for the horse, even though the horse has fewer brain cells than human has (Arenander, 2015).

According to (Clayton, H.M., Kaiser, L.J., de Pue, B., Kaiser, L., 2011) the human and the horse can interact by responding the praise, voice, words, and body language. It means that human's mood influences the horse's mood and vice versa. The main question is: what should a human do when the horse has bad habits? For the reason that sometimes praises and words of encouragement are not enough, this is the other important issue regarding the prefrontal cortex and the dopamine (Arenander, 2015). When the rider's behaviour or mood is changing the horse brain activates fear signals. Although the horse's brain at the beginning acts more vigilantly and becomes more manageable, because of the horse's intelligence. The fear of the horse not only can stop the learning process, but also may cause negative developing of the close, polite, and respectful bond between the rider and the horse. The best way to make the horse calm and able to learn is a moment of the silence after praise. This small break gives the horse an opportunity to relax and think. That is why tactile sensation is very important at that moment and settles the horse back to the mental state in which the horse is able to learn.

There are several numbers of articles related to the human's and the horse's brain behaviour. In the field of our interest is more the brain of the human. For instance, the study (Kim, S.R., Cho, S.H., Kim, J.W., Lee, H.C., Breinen, M., Cho, B.J., 2015) analyzes effects of horseback riding therapy on background electroencephalograms (EEG) of elderly people. The participants were twenty elderly people of 65 or over 65 years old and were randomly divided into two groups: experimental and control, ten people per each group. The experiment took place for fifteen minutes, three times per week for eight weeks. The relative alpha power index was investigated as a background of EEG in both groups, quantitative electroencephalography can be used to diagnose neurological changes in the brain (Kim, S.R., Cho, S.H., Kim, J.W., Lee, H.C., Breinen, M., Cho, B.J., 2015). The electrical flow between neurons through electrodes, which are attached to the surface of the head, can be captured by the established electric signal due to an active change in the brain (Babiloni, C., Ferri, R., Moretti, D.V., 2004). The data was collected using a computerized polygraph (PolyG-I, Laxtha Inc., Korea) and TeleScam, which is real-time analysis program. The participants were surrounded by the calm and relaxing environment. They were asked to close their eyes for three minutes, in order to reduce noises caused by electric equipment and movements of the eyes. Also, the participants were asked not to chew and talk during the EEG test.

The data from EEG was recorded for one-two minutes, such a short time interval can be explained by the possibility of impact by external conditions. According to (Kim, S.R., Cho, S.H., Kim, J.W., Lee, H.C., Breinen, M., Cho, B.J., 2015) the background EEG signals were analyzed based on monopolar derivation from the eight electrodes attached to the surface of the head: Fp1, Fp2, F3, F4, T3, T4, P3, and P4 according to the International 10–20 Electrode System. The relative slow and fast alpha power were analyzed, only the T3 and P4 domains were highlighted for the relative slow alpha power, the activation was observed in all domains in case of relative fast alpha power on every brain map of the participants from exercise group (Kim, S.R., Cho, S.H., Kim, J.W., Lee, H.C., Breinen, M., Cho, B.J., 2015). During the experiment, the alpha wave power, which is an index of stable emotional status and mental health, was reduced in the frontal and temporal lobes (Babiloni, C., Ferri, R., Moretti, D.V., 2004) and (Moraes, H., Ferreira, C., Deslandes, A., 2007). It was physically proven by (Kim, S.R., Cho, S.H., Kim, J.W., Lee, H.C., Breinen, M., Cho, B.J., 2015), that the alpha wave power is more associated with mental stress, stability and relaxation than exercise intensity.

As stated in (Cho, 2017) the study is aimed to identify the effects of real horseback riding and horseback riding using horse simulator on the relative alpha power spectrum in the elderly. There were thirty-one participants all at least 65 years old. The participants were randomly divided into two groups. The first group reflects real horseback riding and consists of fifteen participants. The second one consists of sixteen participants and represents mechanical horseback riding. The experiment took place for twenty-five minutes twice a week for twelve weeks. The participants were selected according to the following criteria: no chronic deceases, such as deteriorative or active disorders, hypertension, diabetes, hepatitis, and renal insufficiency. The same real horse was used for the whole cycle of the experiment. The horseback riding simulator (JOBA, Panasonic EU 6441, Japan) was used in the experiment and is able to repeat the movement of the real horse in three-dimensional motion, such as pelvic tilt and left and back trunk inclination (front and back, left and right, up and down). Numerical EEG should be used for diagnosing neurological changes in the brain of the human. The electrical flow between neurons through electrodes, which are attached to the surface of the head, can be captured by the established electric signal due to an active change in the brain. The collected EEG data were analyzed, monitored and reordered in the same way as it has been already described in the previous paragraph.

The relatively slow and fast alpha power was compared by domain according to the exercise duration, there was not any significant difference in any domains (Cho, 2017). F3, T3, and P3 domains showed a significant difference in interaction, and T4 and P4 domains also exhibited significant differences between the groups. Comparing the relative slow alpha power of the real horse and the simulator there was no change in the group that exercised on the simulator. When the brain activity was examined before and after exercise in the real horseback riding group, brain activity in the T3 domain was highlighted. Comparing the relative fast alpha power of the real horse and the simulator it was concluded that there was more activity in the real horseback riding exercise group and no change in brain activity in the horseback riding simulator group (Cho, 2017). When the brain activity was explored before and after the exercise cycle in the real horseback riding exercise group, brain activity in the T3, P3, and P4 domains was increased (Cho, 2017).

Judging by (Crews, 2009) the existing bond between the rider and the horse was considered using EEG and reading data from the horse and human concurrently. It was suggested that there is a possibility of synchronizing brain patterns between the rider and the horse while interaction. The participants were two female and one male with different riding experience. All participants were riding the same horse. One more horse was tested with the owner due to the determine rider's ability to connect with the familiar and unfamiliar horse. For determining the level of bonding between the human and horse the Pet Bonding Scale (Angle, Blumentritt, & Swank, 1994) was used with 0-32 scaling method and reflects bonding with animals. The EEG data was measured from 10 brain domains such as F3, F4, C3, C4, T3, T4, P3, T4, O2, and O1 using the International 10/20 system (Jasper, 1958). For eye blinks detection the electrodes were attached in the lateral canthus and the superior orbital ridge of the right eye. Moreover, the electrodes were placed behind each ear to linked mastoids. The signal was averaged and subtracted from ten domains. The ground electrode (CZ) was attached to the nose of the horse and to the rider. The data were collected for five conditions, such as condition 1 – the rider and the horse are in separate locations; condition 2 – the rider stands near the horse; condition 3 – the rider pets the horse; condition 4 – the rider groomed the horse; condition 5 – the rider sits on the horse.

The Pet Bonding Scale was created for each rider and the EEG data was checked for eye blinks and issues. The power spectrum analysis was carried out by four ranges of frequency, such as theta, alpha, beta, and beta2. The brain maps were generated from the power spectrum analysis. Female riders achieved 25 and 31 scores in the Pet Bonding Scale, respectively, the male rider got 31 points. It is needed to define if there is any subjective assessment of bonding with animals as an indicator of EEG synchronization, or the bond between the horse and a human. Comparing of different actions applied to the horse by the rider, such as standing, petting, grooming, and sitting shows increasing of EEG synchronization between the horse and the rider. Additionally, the brain map of the female experienced rider with the own horse indicates greater synchronization than with the unfamiliar horde. Increasing of the horse-rider interaction leads to increasing of the EEG synchronization, which shows the good bonding between human and the horse.

1 EQUIPMENT USED IN THE EXPERIMENTS

2.1 Horseback Riding Simulator

Horseback riding simulator (figure 9) was designed and created in Lappeenranta University of Technology. The Mevea motion platform, shown on figure 10, was used as the motion core of the simulator to generate motions for horseback riding simulator by using electrical drive energy. Comparing with the pneumatic or hydraulic system, the energy consumption of the platform is lower, and capabilities are higher. The platform is simply operated due to the ability to use standard PC to control it. The data for the platform was collected using a real horse. The platform is controlled by a Beckhoff PLC, equipped with a Beckhoff basic CPU module CX2030 and Beckhoff CX2100 power supply and UPS module. The Mevea motion platform is 6 degrees of freedom motion platform, operated with six electrical servo actuators. The control is done through Ethernet connection via specific Mevea motion platform controller software. Specifications of the Mevea motion platform are shown in table 1 (Mevea Motion Platform User Manual, 2016). The coordinate system of the 6 degrees of freedom motion platform is shown on figure 11, red, green and blue are x-, y-, and z-axes, respectively.

Figure 9. Horseback riding simulator

Figure 10. The Mevea motion platform

Table 1. Specifications of the Mevea motion platform (Mevea Motion Platform User Manual, 2016)

Degrees of freedom	Surge, Sway, Heave, Roll, Pitch and Yaw
Maximum motions	Surge: ±140 mm, Sway: ±130 mm, Heave: ±86 mm, Roll: ±15 deg, Pitch: ±17 deg, Yaw: ±22 deg
Maximum velocities	Surge: 280 mm/s, Sway: 250 mm/s, Heave: 150 mm/s, Roll: 30 deg/s, Pitch: 30 deg/s, Yaw: 50 deg/s
Maximum accelerations	Surge: 0.7 g, Sway: 0.7 g, Heave: 1.0 g, Roll: 170 deg/s^2, Pitch: 170 deg/s^2, Yaw: 200 deg/s^2
Maximum payload	1200 kg
Center of mass	Center of the upper frame and maximum 0.5 m above the upper frame
Current and voltage	400 V, 32 A
Dimensions	Upper frame: 0.70 x 0.78 m Lower frame: 1.0 x 1.2 m Lowest position height: 0.55 m Cabinet: 100 cm x 80 cm x 30 cm
Weight	120 kg + Cabinet

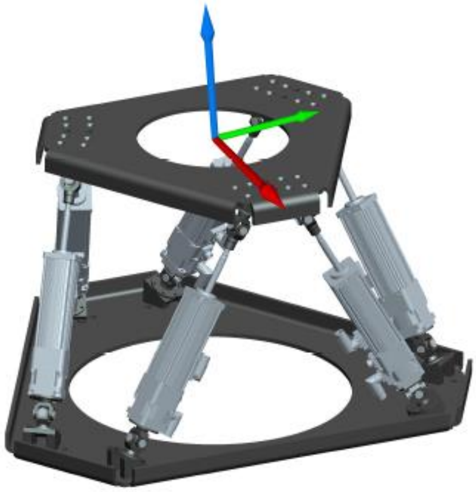


Figure 11. The coordinate system of the 6 degrees of freedom motion platform.

The software used to control the motion platform is Matlab/Simulink and TwinCat with a created real-time interface to control the motion platform. Main Simulink model is shown in figure 12. This model consists of subsystems each of which refers to control the motion platform and changing modes (horse gaits). Subsystem relates to motion platform controlling and visualization is shown on figure 13. Visualization of the TwinCat real-time interface is shown on figure 14.

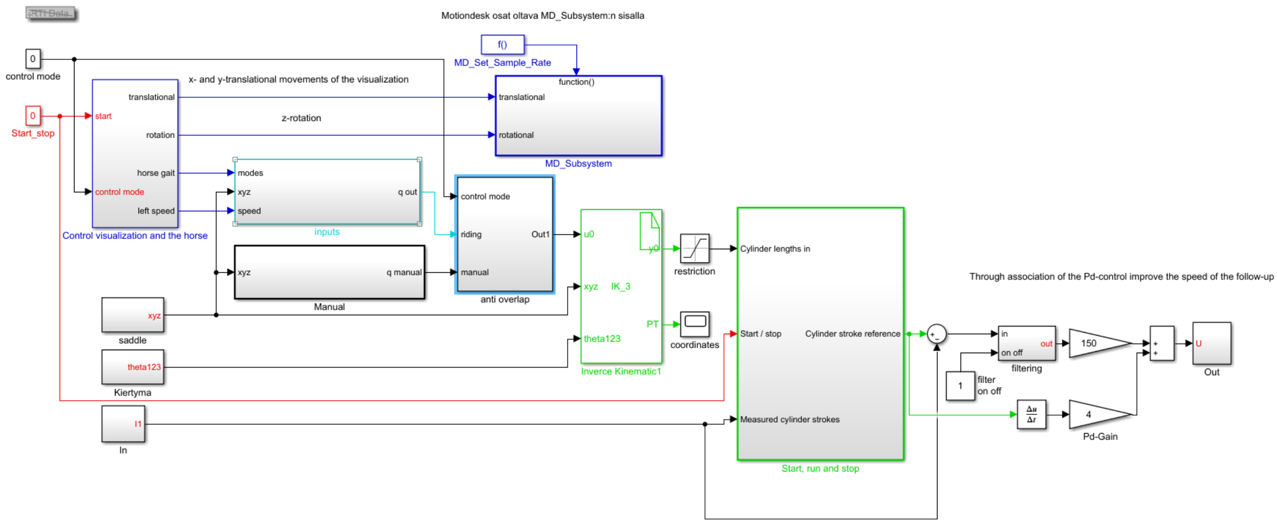


Figure 12. Main Simulink model

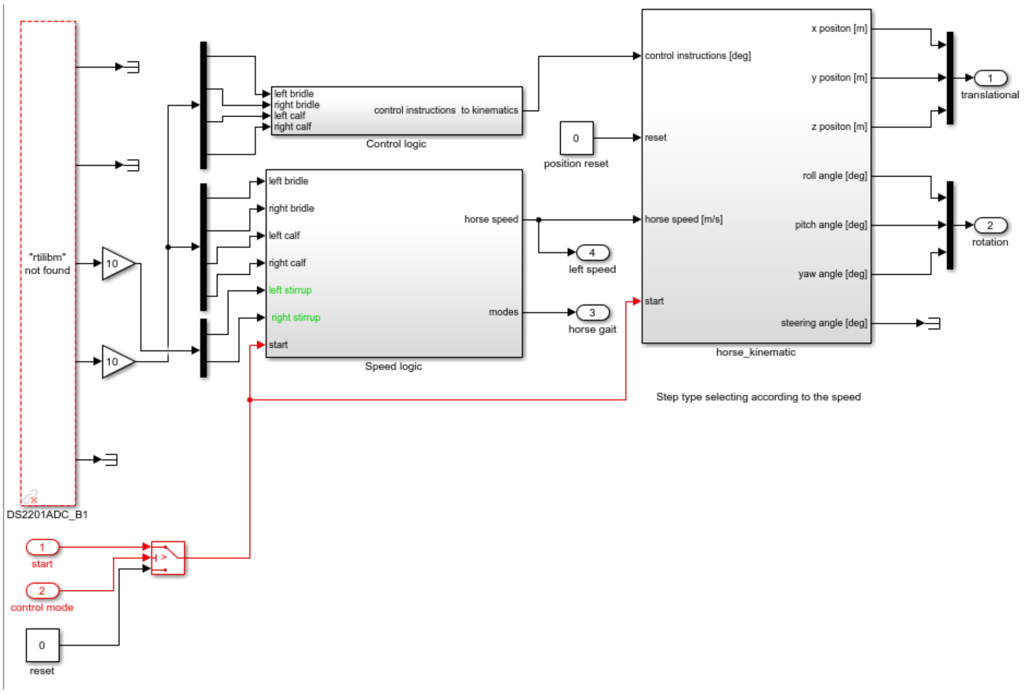


Figure 13. Subsystem relates to motion platform controlling and visualization

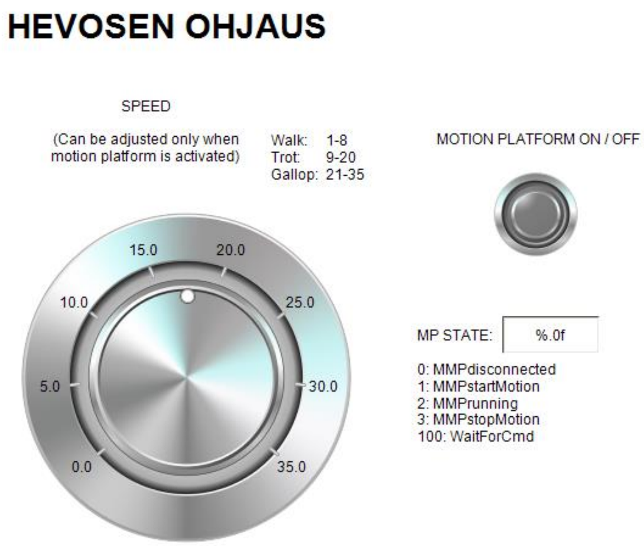
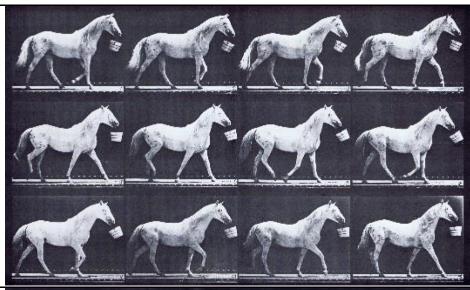
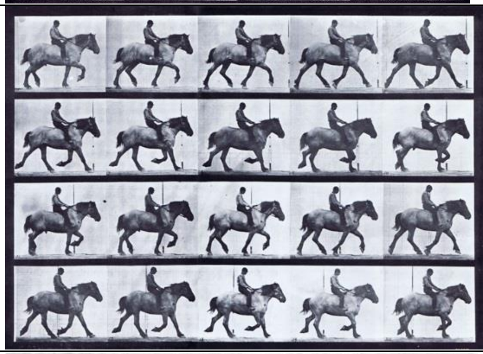
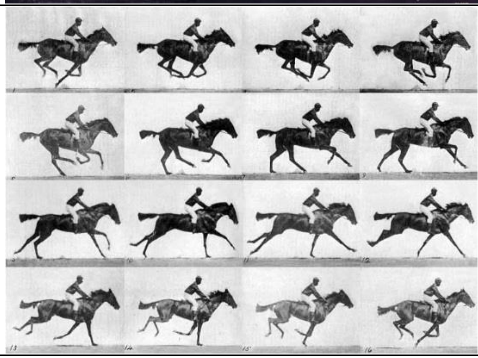


Figure 14. Visualization of the TwinCat real-time interface

The motion platform works in the different modes which vary in speed. Every mode reflects the movement of a real horse implemented into the motion platform. Modes, working speed, and examples of horse movements are represented in table 2 below. Mode "walk" is active at speed from 1 to 8, mode "trot" is active at speed from 9 to 20, and mode "gallop" is active at speed from 21 to 35.

Table 2. The motion platform working modes

Mode	Working speed	Example
Walk	1-8	
Trot	9-20	
Gallop	21-35	

2.2 The Xsens MVN Inertial Motion Capture System

The Xsens MVN is inertial motion capture system, shown on figure 15. Consists from the lycra suit, which is a special system for the motion capture of the human body. With the help of biomechanics, sensors and wireless communication, the system is based on inertial motion capture method. The Xsens MVN suit (Rosenberg, D., Luinge, H., Slycke, P., 2009) consists of 17 inertial MTx sensors, which are attached to key areas of the human body. The system is able to detect human body with changing in position and orientation using gyroscope and accelerometer. Also, the system consists of 23 biomechanical models similar to the body of the real person and 22 joints. The inertial based motion capture system is able to correct drifts and errors automatically.

Figure 15. The Xsens MVN inertial motion capture suit

The inertial based motion capture system is fully portable, easy to use everywhere like office, outdoor area, laboratory and so on without special attachment to the particular place (MVN User Manual, 2016). Also, the system does not have any restrictions in measurements range (except wireless). The Xsens MVN inertial motion capture suit is a full body inertial kinematic measurement system, incorporating synchronized video data, providing three-dimensional orientation with accuracy 1^{o} (Van den Noort, J., Schotles, V.A., Harlaar, J., 2009). The system is providing an instant graphical output with joint angles included. With implemented C3D exporter, imported MVNX (XML) output it is easy to receive joint angle data, the centre of mass and factory calibrated sensor data. Real-time and offline data monitoring, recording and editing can be made using software called MVN Studio. The MVN Studio uses sensor fusion algorithms to produce absolute orientation values, which are used to transform the 3D linear accelerations to global coordinates (Skogstad, S.A., Nymoen, K., Høvin, M., 2011).

There are two different kinds of motion trackers that can be used during measurement sessions. The first kind includes two types of motion trackers: the single MTx (Figure 16) used as end trackers and the string of three MTx-STR (Figure 17). The motion trackers, MTx, and MTx-STR are the miniature inertial measurement units containing 3D linear accelerometers measuring accelerations including gravitational acceleration, 3D rate gyroscopes measuring angular velocities, 3D magnetometers measuring the (earth) magnetic field, and a barometer, which measures atmospheric pressure. These trackers are placed at strategic locations on the body (fixed by the suit), to measure the motions of each body segment. The trackers of the system usually placed on the following locations such as pelvis, sternum, hands and head. These parts of the human body take the greater part in horseback riding. The MTx-STR's are used to chain the legs (upper leg, lower leg, and feet), as well as for the upper body (shoulders, upper arms, and for-arms).

Figure 16. Motion Tracker (MTx)

Figure 17. Motion Tracker (MTx-STR)

The second kind is a wireless motion tracker (MTw) (Figure 18). The motion tracker MTw is the miniature inertial measurement provides 3D angular velocity using rate gyroscopes, 3D acceleration using accelerometers, 3D earth magnetic field using magnetometers, as well as the barometer for measuring atmospheric pressure (MVN User Manual, 2016). The tracker can be placed in any location on the human body, usually on the lower back and fixes with the suit. The MTw is an excellent measurement unit for orientation measurement of human body segments, in particular, because it is also designed to maintain very high accuracy time synchronization of the individual sensor readout across a wireless network of multiple units (MVN User Manual, 2016). This is very important while joint angles measurements session is in process. The MTw is using a LiPo battery, with the help of the battery the device can be used maximum for 6 hours or withstand 90 hours of charge without using in sleeping mode. It will be fully recharged after one hour docked in a wall powered Awinda Station (MVN User Manual, 2016).

Figure 18. Motion Tracker (MTw)

2.2.1 Calibration

The system should be calibrated before the recording is started. There are three types of calibration that can be selected in the software: N-pose (neutral pose), T-pose, and expert calibration (hand touch).

2.2.2 Calibration using N-pose (Neutral Pose)

This is a basic way of calibration. Neutral pose, shown on figure 19, calibration can be implemented as a stand calibration for an individual or first step before the hand-touch calibration. When performing a neutral pose calibration, the user must be sure about the following points:

- Stand upright on a horizontal surface;
- Feet are located parallel, one-foot width apart;

- Knees are placed above feet;
- Hips are situated above knees;
- Back is straight;
- Shoulders are located above hips;
- The arm is vertically straight alongside the body, thumbs are forwards. The forearms should move only in the vertical (sagittal) plane with the palms of the hands facing each other;
- The face is forward;
- Movement is not allowed during the calibration procedure. (MVN User Manual, 2016).

After checking that all points of calibration are done, if the legs on the 3D model in the software are crossed, when the feet are together, it means that during calibration there was a mistake and feet was too far from each other during the calibration procedure (MVN User Manual, 2016). The procedure of calibration should be repeated ones again with feet closer to each other for reaching better results.

Figure 19. N-pose

2.2.3 Calibration using T-pose

This is the other basic calibration pose. The T-pose, shown on figure 20, is recommended when the investigated object cannot hold arms vertically close to the body. When performing T-pose calibration, the user must be sure about the following points:

Stand upright on a horizontal surface;

Feet are located parallel, one-foot width apart;

- Knees are placed above feet;
- Hips are situated above knees;
- Back is straight;
- Shoulders are located above hips, do not pull the shoulders up;
- Arms are extended horizontally, thumbs are forwards. The forearms should move only in the horizontal (transverse) plane;
- The face is forward;
- Attention should be paid to symmetry, for instance, the arms should be kept at an equal height;
- The elbow should not be overextended since flexion or extension may be projected in other axes;
- The wrists, elbows and shoulders should all be located on a single line.

Figure 20. T-pose

2.2.4 Expert Calibration: Hand Touch

In general, Hand Touch calibration is not necessary. Expert calibration made only at the discretion of the operator. When the user needs good hand data or there is a special occasion Hand Touch calibration should be used. It is important to do the N-pose calibration before, to obtain better results. When performing Hand Touch calibration, the user must be sure about the following points:

- The palms of the hands are placed together;
- Movements are shown on figure 21 should be repeated;

- The hands should be moved around slowly while keeping the hands together;
- The elbows should be kept in the same position for 10 seconds;
- Different movements, especially, making small circles in all directions, should be performed. (MVN User Manual, 2016).

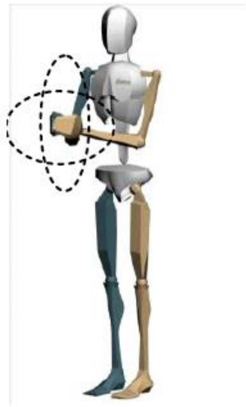


Figure 21. Hand Touch calibration pose

2.3 NaturalPoint OptitTrack Motion Capture System

NaturalPoint OptiTrack is the optical infrared marker-based motion capture system. The optical infrared marker-based motion capture system is based on several cameras with the ability to detect with built-in diodes the infrared materials which markers are covered. The infrared light from the cameras is reflected by reflective markers and captured by the camera as 2D point display images, the system calculates the 3D position in the capture space of all marker used in the experiment by combining multiple of 2D images (Skogstad, S.A., Nymoen, K., Høvin, M., 2011). The calibration is necessary before using the system. After calibration, each camera finds own position and location in the global coordinate system and in the captured frame. While putting a group of markers needed to create rigid bodies software automatically determine body segments and complete the whole skeleton. A rigid body is a solid body without any deformation or with very small deformation that can be neglected. The motion capture system is able to recognize the object and determine its position and orientation using at least three markers placed on the rigid body in a unique and asymmetrical pattern. A skeleton is called a combination of rigid body and markers, which are placed to the rigid body in a specific way by the rules how they relate to each other.

It is assumed that the lower part of the right thigh is connected to the top part of the right calf, as they can rotate only around one axe, in a human skeleton model. OptiTrack Tracking Tools is custom software using for calibration, creating cameras system, markers monitoring and data analyzing.

2.3.1 Camera System

The Flex 3 V1002 camera, shown on figure 22, is a special device for integrated image capture, processing, and motion tracking. With the help of Flex 3, a variety of pre-processed image types can be sent to the personal computer (PC). As a result, bandwidth and central processor (CPU) load are reduced, also there is more effective tracking of the motion. (Tracking Tools 2.4.0 User's Guide, 2012). Types of image processing include:

- Precision grayscale – is the most accurate type of marker recognition. Precision grayscale installed on camera by default. This processing type sends information about the marker to the computer. After transferring the following parameters of the markers is calculated: location, size and orientation. This method considers as the most accurate but requires a camera USB connection to the computer and uses more computer resources.
- Segment – is a balanced marker detection type. Segment method is similar to Precision Grayscale. This method is something average between requiring camera USB connection to the computer and using computer resources.
- Object – is the most CPU-efficient marker recognition. This method requires more camera USB bandwidth to the computer and transfers less information about the marker to the computer.
- MJPEG-compressed grayscale – this method uses the properties of the grayscale frame for maximum and transfers high-quality video information.
- Raw grayscale – is a full resolution, uncompressed grayscale frames.

Figure 22. OptiTrack Camera Flex 3 V1002

In order to detect markers, several OptiTrack cameras should be placed quite close to each other for having overlapping field of vision. This is how an area called a capture volume for tracking is created. Cameras are located in the way that the marker within any region of the capture volume should be visible at least for two cameras, in an ideal way even more. Cameras placement and aiming should be arranged with respect to the place, where the most capture is taking take place for better overlapping fields of vision of the cameras. If the camera is installed on the wall, bar or beam it is better to use special mounting equipment for fixing its position before utilizing. Any camera's movement or camera mounting hardware after calibration may cause troubles and recalibrate. The Flex 3 V100 has maximum mount stud depths of .225". Damaging of the camera may occur if a longer stud is used. (Tracking Tools 2.4.0 User's Guide, 2012).

If the same camera system has several cameras they usually divided into smaller camera systems for creating bigger capturing environment or for increasing the existing motion capture frame frequency. Synchronizing capturing using different camera systems helps to implement various tracking frames. In addition, for achieving higher frame rates with an alternate configuration camera groups can be used. To avoid cameras overlapping capture, the cameras are divided into groups with different gate synchronization displacement. (Tracking Tools 2.4.0 User's Guide, 2012).

Table 3. OptiTrack Camera Flex 3 V100R2 Parameters (Tracking Tools 2.4.0 User's Guide, 2012)

Frame Rate	100 FPS
Resolution	640 x 480
Filter Switcher	Optional
Bundled Software	n/a
Single-device Multi-Camera Tracking	No
Maximum Units Per Workstation	24
Maximum Range (Using ¾ inch markers)	36 feet[3], 11 meters
Stock Lens (Horizontal FOV)	46^o
Optional Lenses (Horizontal FOV)	38^o, 58^o
Interface	USB 2.0
Synchronization Method	Wired and OptiSync
Image Processing Modes	Precision Grayscale, Segment, Object, and MJPEG
Number of LEDs	26
LED Strobe Mode	Yes
LED Intensity Control	Yes
Shutter Type	Global
Electronic Exposure Control	Yes
Frame Rate Control	Yes
Camera Body	Aluminium
Standard Tripod Mount (-20 thread)	Yes

Cameras are synchronized by using OptiSync. OptiSync is special NaturalPoint's utility tool to synchronize cameras by USB using OptiHubs. OptiSync is only available when using Flex 3 V100R2 cameras to connect them to OptiHubs, with no extra synchronization cable. Multiple OptiHubs in a camera group may be connected by a hub to hub using synchronization cable in a custom slot called Hub SYNC Out. It is technically possible, to use combined Wired Sync and OptiSync configurations but they are not officially supported. (Tracking Tools 2.4.0 User's Guide, 2012).

2.3.2 Calibration

The most superior way of calibration of OptiTrack's cameras is three marker technique. This way of calibration supplies greater accuracy of the system and allows more flexible cameras positioning. Three markers calibration method requires the OptiWand, shown on figure 23, and is able to work with any version of Tracking Tools 2.2.0 or higher. The OptiWand is a special wanding calibration tool, which is presented in different sizes. In current work, the OpiWand wanding tool is 500 mm large. (Tracking Tools 2.4.0 User's Guide, 2012).

Figure 23. OptiWand calibration tool

Another way of calibration is one marker method, which can be used in the last systems. The one marker method is recommended to use if there is no opportunity to use three marker calibration method. Three marker calibration method is assumed to be the newest calibration technology with more convenient and reliable technique. One marker calibration method is based on the wizard with one marker with four buttons located on a bar. With the help of this method and calibration tool the interface is divided into two sections with two options, which simplify using the application. (Tracking Tools 2.4.0 User's Guide, 2012).

The major method of calibration the desired capture volume frame in the NaturalPoint's Tracking Tool software is wanding. The one or three markers method is based on the wand waving into the desired capture volume when cameras are turning on and taking samples. When data is collected, the physical position (extrinsic) and lens characteristics (intrinsic) of the cameras are defined. Careful and proper wanding is obligatory for a good calibration. While doing calibration the wanding tool should be slowly moved through the all capture volume to cover as much space as possible for good sampling. For achieving better result wanding should be waved equally, thoroughly, and comprehensively throughout the volume. The volume can be differed depending on camera aiming and setup. All three markers of the wanding tool should be used at the same time and captured by each camera for successful calibration. The path and angle should also change within a specific range in relation to the camera due to covering different perspectives to record the data. (Tracking Tools 2.4.0 User's Guide, 2012).

After the procedure of completed wanding the software provide the results in numbers of the calibration by investigated samples. There is sufficiency rating included in the feedback. The rating specifies the minimum number of recorder accurate samples in the following order low, medium, high and high quality. Greater volumes require high sample quality. If the six-camera system is using approximately 1000 samples per one camera will be recorded while calibration. To obtain a higher quality results, one camera should record around 200-225 samples camera multiplied by the number of cameras. (Tracking Tools 2.4.0 User's Guide, 2012).

The method based on three marker calibration goes through different steps, is able to adjust dynamically, and allows the user to take significant control over the required time and concluding accuracy of the whole system. After finishing calibration there is a calculation process, which covers every collected sample point and shows the result in rating from low to the top for each camera in the volume. There is also an overall quality selection of the current calculation. Additionally, it displays the calculated focal length, standard deviation, and errors. Mean errors strongly influence on the quality rating and updating according following order from low to high Poor, Fair, Good, Great, Excellent, and Exceptional. (Tracking Tools 2.4.0 User's Guide, 2012).

The automated correct and optimal stages activate the calculation process. According to the user’s manual, the first stage is "Refine initial solution", the second stage is "Global Optimization: Initial" and the last stage is "Global Optimization: Final". The system moves from the first stage to the next stage automatically, under the condition that each stage of calibration was completed successfully in details. Each camera should reach at least “Good” for sufficient motion tracking but recommended to reach “Excellent”. If the calculation phase reaches “Exceptional”, it means that after the solver hits the reducing point, as it takes extremely long to calculate small samples in term of calibration and hard to reach desired quality. For high calibration quality the mean error accounts maximum 0.145 on every single camera. (Tracking Tools 2.4.0 User's Guide, 2012).

2.3.3 Ground Plane

When the camera system is calibrated, a ground plane, shown on figure 24, is used with desired capture environment to determine the coordinate system according to 3D positioning. The ground plane is a metal bar in form of the L-shape with markers attached to the edges. The ground plane also has a shape of the 90-degree angle. The angular marker is placed in the corner of the ground place and refers to the centre of the coordinate plane. The long arm of the ground plane is 400 mm and reflects the positive Z-axis. The short arm of the ground plane tool is 300 mm and shows the negative X-axis as right-handed coordinate plane installed by default as the coordinate plane. It is assumed that the top of the ground plane is the top position on the plane with the markers on the party and refers to the Y-axis. (Tracking Tools 2.4.0 User's Guide, 2012).

Figure 24. The ground plane calibration tool

After volume calibration is done, the calibration tool is used to determine the coordinate system. The length of the vertical axis is accounted 53 mm and refers to the ground and the centre of the plane. This dimension provides the software to determine the location of the ground when putting the device to the desired surface with the X and Z-axes. The Y-axis stays static until the surface conditions are static also. In the case, when the surface is not static the distance between the centre of the markers and X-Z plane should be measured and manually entered the value into the software in millimetres. (Tracking Tools 2.4.0 User's Guide, 2012).

2.3.4 Motion Capture Markers

Optical system work based on using data captured from the image sensors for triangulation the 3D position of the subject, which is placed between at least two cameras calibrated to supply overlapping projections. For data collection, the markers are placed to a desired motion captured object. However, recent systems allow capturing surface characteristics depending on the characteristics of the studied object with producing clear data. Monitoring a bigger number of objects and expansion of motion capture frame is able by increasing the number of using cameras. Such systems collect three degrees of freedom data for every marker. For three or more markers rotational information creates from relative information. For instance, the angle of the knee is performed by the hip, knee and ankle markers. There are several kinds of motion capture markers existing for tracking needs.

Passive markers. Passive optical systems use markers covered with a special retroreflective material to reflect generated light near the camera’s lens. The camera’s limit can be regulated to reflect only bright retroreflective material of the marker, other materials such as skin and fabric will be ignored. The geometric centre of the marker can be alleged as a two-dimensional image position for capturing. For camera calibrating and obtaining camera’s position, an object with attached markers to the known position (calibration tool) is used. A three-dimensional fix obtains only if two calibrated cameras see the marker. The usual system consists of two to forty-eight cameras.

For reducing marker replacements, it is possible to create a frame with a large number of cameras, for example, one hundred or more. Additional cameras provide full coverage of the motion capture frame and allow to track more than one object at the same time. Using the passive markers-based motion capture system the studied object does not need to wear any other electronic equipment. The equipment used in the systems is markers as small rubber balls fixed with a tape to the segments of the body. In biomechanics, the markers usually placed directly to the skin. Sometimes, the markers attached to a special suit made from spandex or lycra designed specifically for motion capture. The passive marker system is able to capture numerous numbers of markers.

Active markers. The active markers-based motion capture system working principle is the fast highlighting of the relative position using one or several LEDs at the same time, data processing in real time and as a result allows to obtain triangulate position. Instead of reflecting generated externally light back, the markers emitting the own light. The capturing distance and volume can be increased by using square law with activating a high signal-to-noise ratio. As a result, the quality of measurement session is extremely high and marker oscillation is low. There are several examples of TV series and movies (Van Helsing, Rise of the Planet of the Apes) produced episodes using this technique.

The main benefit of the active markers-based motion capture system compared to other optical systems is that the actor can move freely around props making capturing significantly harder. Each marker has unique identification in the active markers-based motion capture system and installed frame. The method of identifying each marker is valuable in real-time applications. It is also possible to reveal the position using coloured LED markers, each colour is given to a particular spot of the body. One of the first active markers-based motion capture systems was created in 1980. That system was a combination of active marker-based and passive marker-based motion capture system. The creators used rotating mirrors and glass markers coloured in bright colours.

Time modulated active marker. The active marker-based motion capture system is able to track one or several markers at the same moment of time, usually 0.01 seconds. While tracking the amplitude of every single marker assigns to the marker as its ID. Using marker ID this method is assumed to be more accurate compared to other methods of motion capturing. Camera system suitable for that kind of tracking has real-time processing and synchronization. Additional processing mounted in cameras for high resolution and speed. Markers are covered with a special material which is not affected by sunlight that makes the system suitable to use outdoors. While capturing, the high-speed electronic shutter allows the system creates from up to 960 frames per second. Low operational costs can be decreased by computer processing of modulated IDs without filtering. These systems have greater accuracy and resolution, unlike passive technologies. The main drawback is that these systems are extremely expensive.

Semi-passive imperceptible marker. This method is completely different from other techniques, based on high-speed cameras. Some systems use economical multi-LED high-speed emitters. The system uses photosensitive marker tags with photosensors for decoding the optical signals, instead of retro-reflective or active light emitting diode (LED) markers. Location, orientation, lighting and reflectance of every tracking point can be calculated by the tag. The tags are not affected by sunlight that makes the system suitable to use outdoors and can be easily integrated into normal clothes. The system has no limitations for the number of tags tracking at the same time. Each tag uniquely identifying and removing marker reacquisition issues. The system does not require high data bandwidth as there are no high-speed cameras.

2.3.5 Marker Placement

There are multiple combinations of marker placement to the human body. This is the standard marker placement. There are general rules before starting marker placement:

- tight clothes should be dressed on the experimental person;
- the markers should be placed as close as possible to the bone and stay fixed while tracking;
- the placement of the marker should be asymmetrical, then motion capture system can easily detect the left and right segments of the body of an experimental person.
- Shoulder. The marker is attached to the collarbone. This area should be a static place when the arm goes up and down. The marker is attached asymmetrically to the other side.
- Clavicle. The marker is attached between the two shoulder bones and below the beginning of the neck;
- Elbow. The marker is attached to the area of the upper part of the arm and forearm connection. Also, this area should be a static place when the arm goes up and down;
- Left and Right Hands. The marker is attached to the case of the ring and index fingers, respectively;
- Upper Arm. The marker is attached to create a triangle shape to the upper part of the arm on the line between shoulder and elbow markers. The marker is attached asymmetrically to the other arm;
- Forearm. The marker is attached to the radius bone. The marker is attached asymmetrically to the other forearm;
- Sternum. The marker is attached to the beginning of the rib cage in middle position. For females, the marker should be kept in a stable position while moving;
- C7. The cervical vertebrae bone is located on the spine where the neck ends, and the bone sticks out if the person bends the head down;

- T10. The thoracic vertebrae bone is also located on the spine along the same line with cervical vertebrae bone, ten bones down from cervical vertebrae bone. The marker is attached to the 10th vertebrae. The spinal column is observing better while bending down and pushing the shoulders inward.
- Pelvis. The marker is attached to the area of the pelvic region where the bone is stuck out;
- Back Waist. The marker is attached to the area of the hip from the back side that sticks out. This area is located at the end of the back before the buttocks start;
- Foot. The marker is attached to the bone before the toe starts for left and right feet. The second marker is attached to the bone before the pinky toe starts for left and right feet;
- Ankle. The marker is attached to the area of another part of the ankle bones connection. The marker is attached above this the area and along the connection line from one side to the other;
- Heel. The marker ball is attached to the heel bone. The line that connects the toe and heel markers should be parallel to the ground;
- Knee. The leg should be swung back and forth. The lowest static area of the upper leg should be found. This area refers to the bone which is located above the round knee joint. The marker is attached about 0.5 cm above the knee between the upper part and the lower part of the leg. This area should be a static place when the lower part of the leg swings forward and backwards. For females, the marker is attached more front. Almost every marker put to the muscle should point more to the back to the static area and prevent the marker's movement;
- Thigs. The marker is attached to the sticks out parts of the hips to the side of the body. This area is located below the pelvis. The marker is attached to the said area along the line of the bone and knee markers connection. The marker is attached asymmetrically to the other thigh;
- Leg. The marker is attached to the leg to create a triangle shape. The first edge of the triangle connects knee marker with ankle marker, the second one connects ankle marker with another party of the ankle bone, the third connection line is the line between another party of the ankle bone and the knee marker.

2.4 Neuroelectric Cap Enobio 32

Enobio 32 by Neuroelectrics is a wearable, wireless electrophysiology sensor system, shown on figure 25, for the recording of EEG (but it can also be used for monitoring EOG, ECG or EMG) to monitor brain behaviour. The device has been developed for use in medical environments such as clinics, hospitals, laboratories, research centres or home healthcare environment. The device also can be used for the big amount of data collection from different people in natural surroundings. With the help of electroencephalography, as noninvasive neuroimaging technique, recording the electrical activity of the brain is possible. For detecting the voltage fluctuations special electrodes attached to the head are used. Detecting the voltage fluctuations is possible due to the ionic current in the brain neurons. The positioning of twenty-one EEG electrodes are possible and, besides, intermediate positioning, according to the 10-20 international system. The location and nomenclature of electrodes positioning are approved by the American Electroencephalographic Society. (Neuroelectrics User Manual, 2014).

Figure 25. Neuroelectric cap Enobio 32

The measurements of the EEG can be bipolar or polar. There are two methods of measuring: formal and latter. With the help of the first formal method of measuring it is possible to measure the potential difference between a pair of electrodes. With the help of the second latter method of measuring it is possible to determine the electrode potential compared with a reference. By the signal from the separate electrode or the average measurement from two or more electrodes, it is usually assumed as the reference. For analyzation of the EEG data measurement sessions, spectral methods are used to determine frequency bands. Frequency bands are also called brain waves. The five most common frequency bands are listed below.

- delta (0 - 4 Hz);
- theta (4 – 8 Hz);
- alpha (8 - 13 Hz);
- beta (13 – 30 Hz);
- gamma (30 - 50 Hz).

Critical information concerning the brain function is represented by waveforms. Waveforms are useful in helping to diagnose epilepsy, sleep disorders, coma or cerebral death. A particular feature that distinguishes electrophysiology from other neuroimaging techniques is that electrophysiology provides high-temporal and high-spatial resolutions. In practice, electrophysiology frequently has a combination with magnetic resonance imaging (MRI) or computed tomography (CT) for better achievements in diagnose tumours, stroke and other brain disorders. The electrophysiology results are helpful in analyzing event-related potentials (ERP's) studies connected with visual, somatosensory and auditory stimuli. (Neuroelectrics User Manual, 2014).

2 EXPERIMENTS, RESULTS AND DISCUSSION

3.1 Motion Capture Based on Inertial Experiment

The experiment took place in the simulation laboratory of Lappeenranta University of Technology where horseback riding simulator is located. Two people participated in the experiment. The first person is a male non-professional rider at the age of 20, height 180 cm and weight 77 kg never experienced riding procedure before, shown on figure 26.

Figure 26. Non-professional rider during the experiment

The second person is a female professional rider at the age of 22, height 165 cm and weight 58 kg with 13 years of horseback riding experience, shown on figure 27.

Figure 27. Professional rider during the experiment

The aim of the experiment was to compare the body behaviour of the professional and non-professional riders while riding a horseback simulator with attention to the pelvis of riders using inertial motion capture system. In general, six modes were selected for data collection, such as a slow walk at speed 1, fast walk at speed 5, slow trot at speed 10, fast trot at speed 20, slow gallop at speed 25, and fast gallop at speed 35. The whole representation of the experiment in numbers can be found in table 4. Data were collected during 10 seconds with a time step of 0.00416 seconds for each mode.

Table 4. Motion capture based on the inertial method

Mode	Speed	Duration	Frequency of data collection	Time step
Slow walk	1	10 seconds	240 Hz	0.00416 seconds
Fast walk	5	10 seconds	240 Hz	0.00416 seconds
Slow trot	10	10 seconds	240 Hz	0.00416 seconds
Fast trot	20	10 seconds	240 Hz	0.00416 seconds
Slow gallop	25	10 seconds	240 Hz	0.00416 seconds
Fast gallop	35	10 seconds	240 Hz	0.00416 seconds

Data were recorded using the Xsens MVN Studio software with the fixed pelvis. An example of recorded data is shown on figure 28.

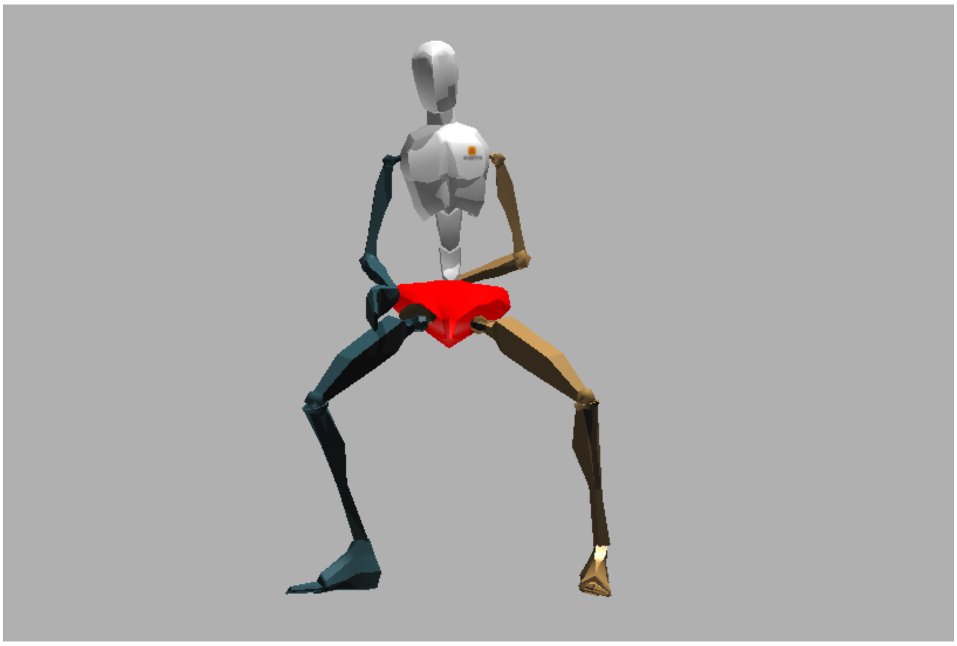


Figure 28. Recorded data from MVN Studio software. Coronal anterior view

Parameters such as acceleration, angular velocity, orientation, position, and velocity were analyzed. Some data needed to be filtered, for instance, acceleration, angular velocity, and velocity. Data filtering was made with the help of the following software: Xsense MVN Studio, Microsoft Excel, and Matlab. Firstly, the project in Xsence MVN Studio was resaved with a different format (.mvnx). It was made in order to open the export project to Microsoft Excel and Matlab. Secondly, data was transferred to Microsoft Excel, divided by parameters to observe and normalized into the equal time strides for each parameter. For the professional rider, time strides account 2600 points and for the non-professional rider, time strides account 2200 points. The last step was data filtering using self-written Matlab script with a low-pass filter. The example of not filtered and filtered acceleration data for slow walk gaits of the horseback simulator for the non-professional and professional rider is shown on figures 29, 30 and figures 31, 32, respectively, where the x-axis is yellow, the y-axis is red, the z-axis is blue.

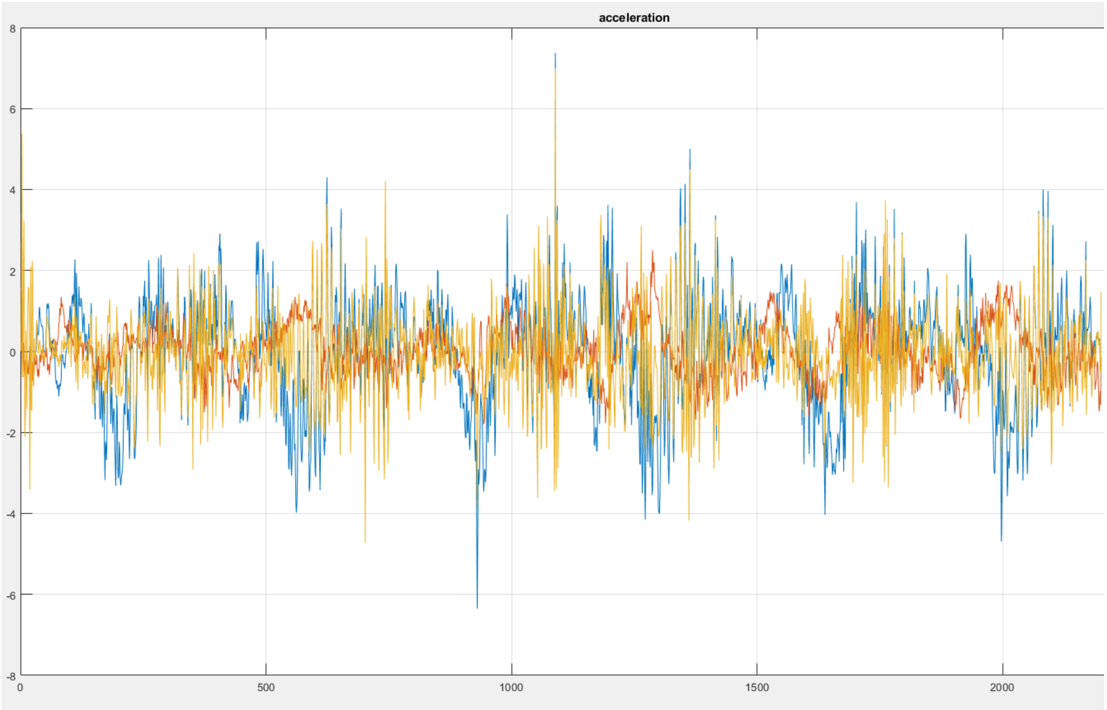


Figure 29. Slow walk not filtered acceleration data for a non-professional rider

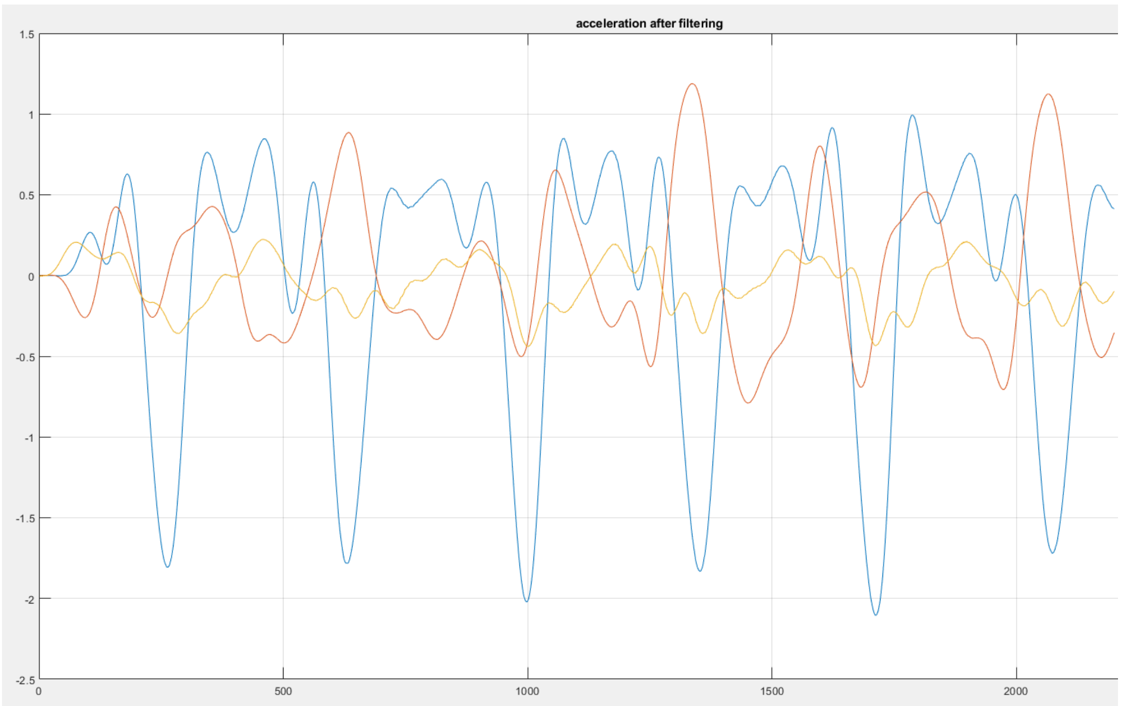


Figure 30. Slow walk filtered acceleration data for a non-professional rider

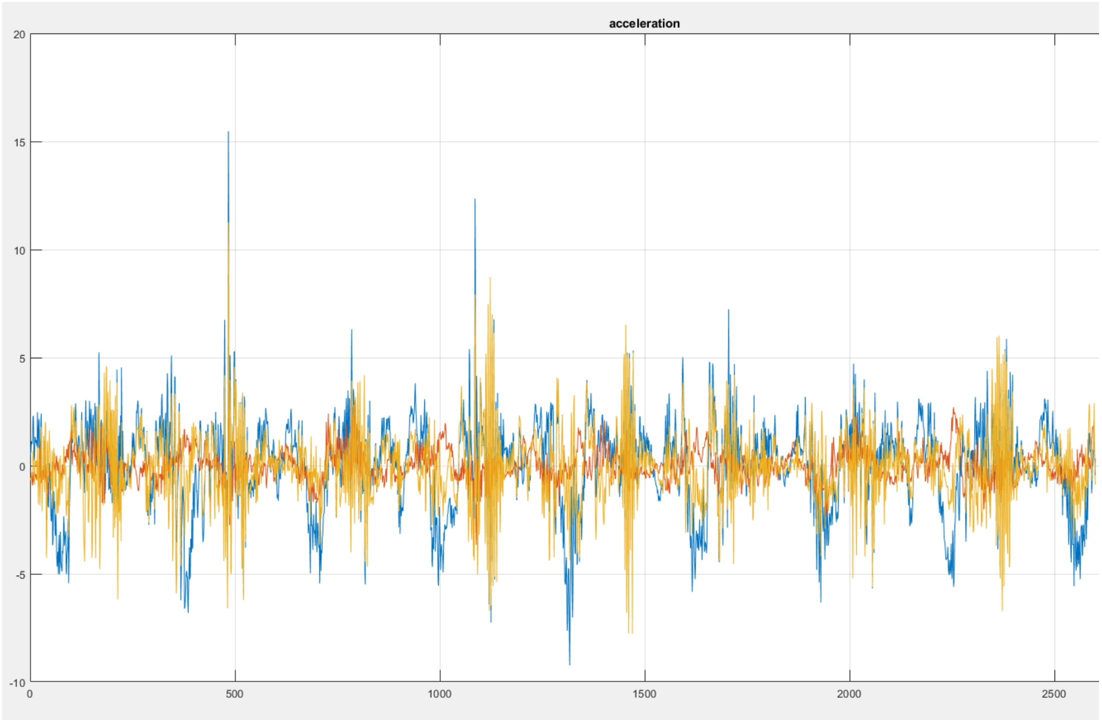


Figure 31. Slow walk not filtered acceleration data for a professional rider

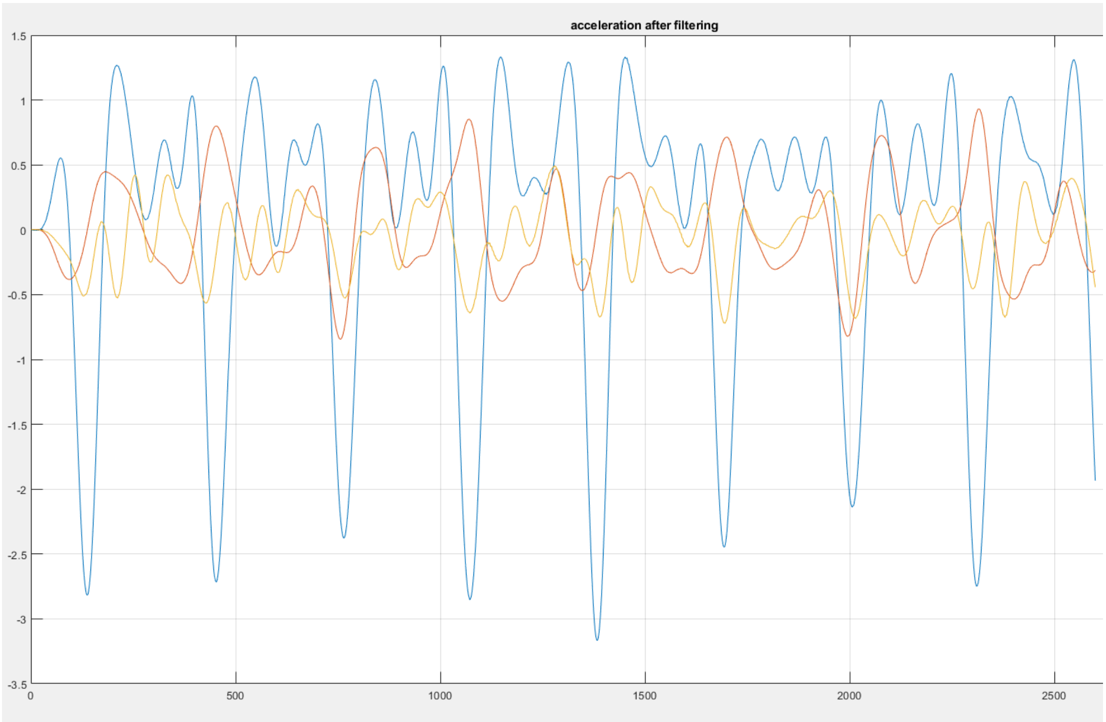


Figure 32. Slow walk filtered acceleration data for a professional rider

Filtered acceleration data for the rest of gaits such as fast walk, slow and fast trot, slow and fast gallop for the non-professional and professional rider, respectively, is shown on figures 33-42 below.

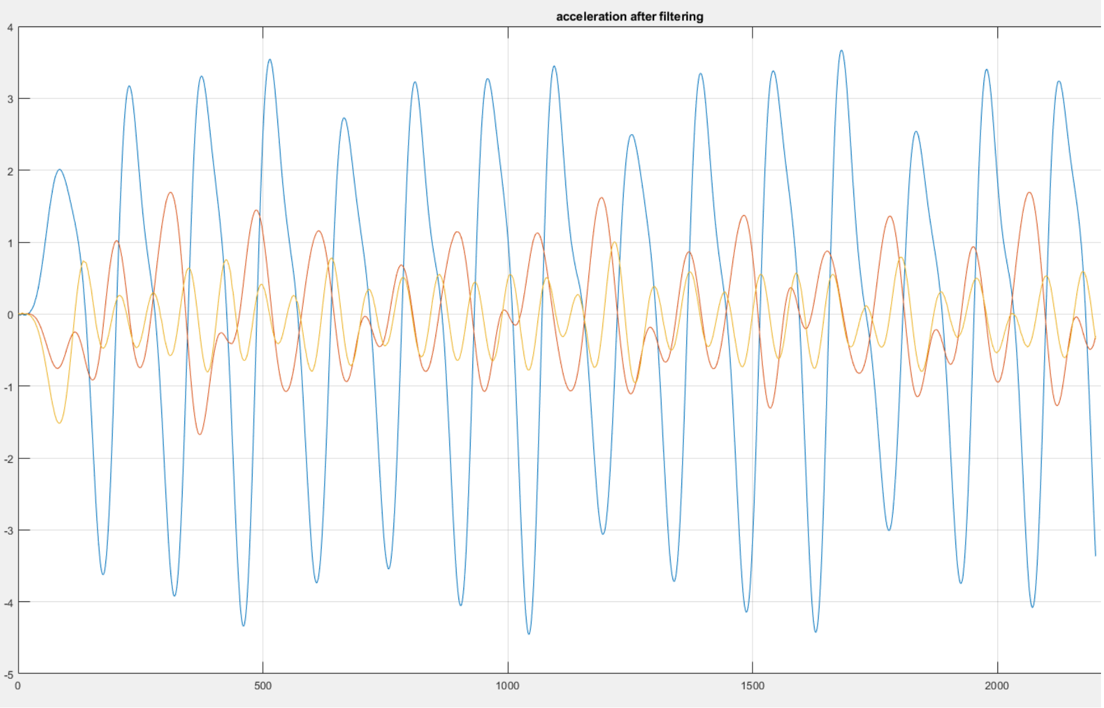


Figure 33. Fast walk filtered acceleration data for a non-professional rider

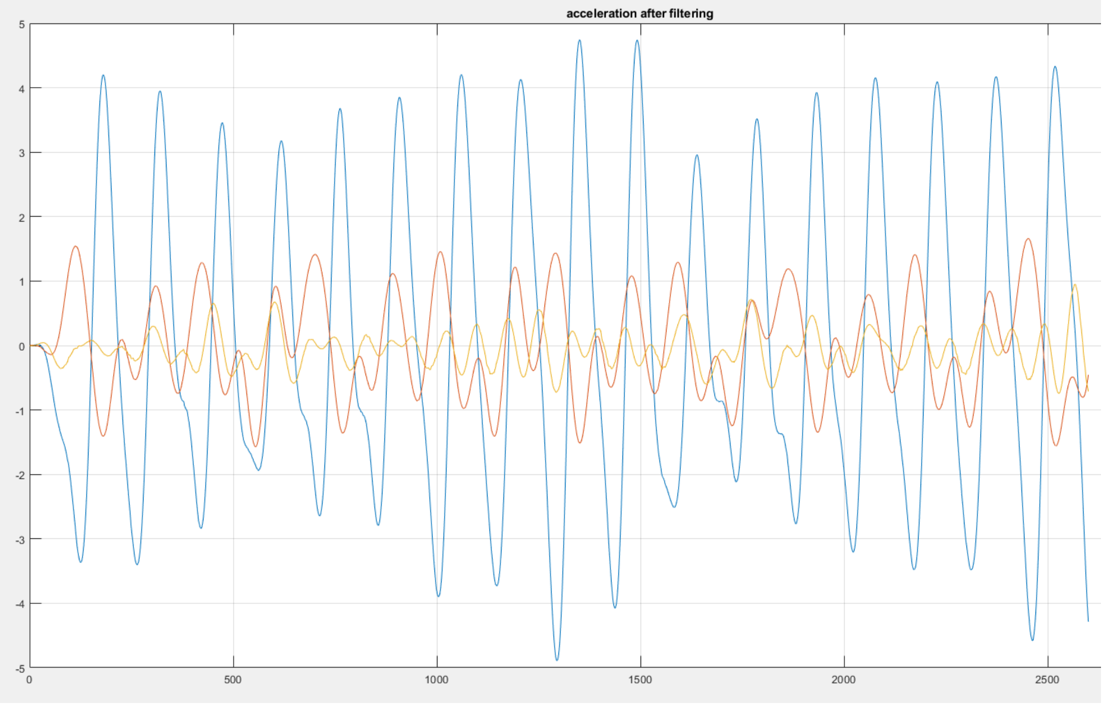


Figure 34. Fast walk filtered acceleration data for a professional rider

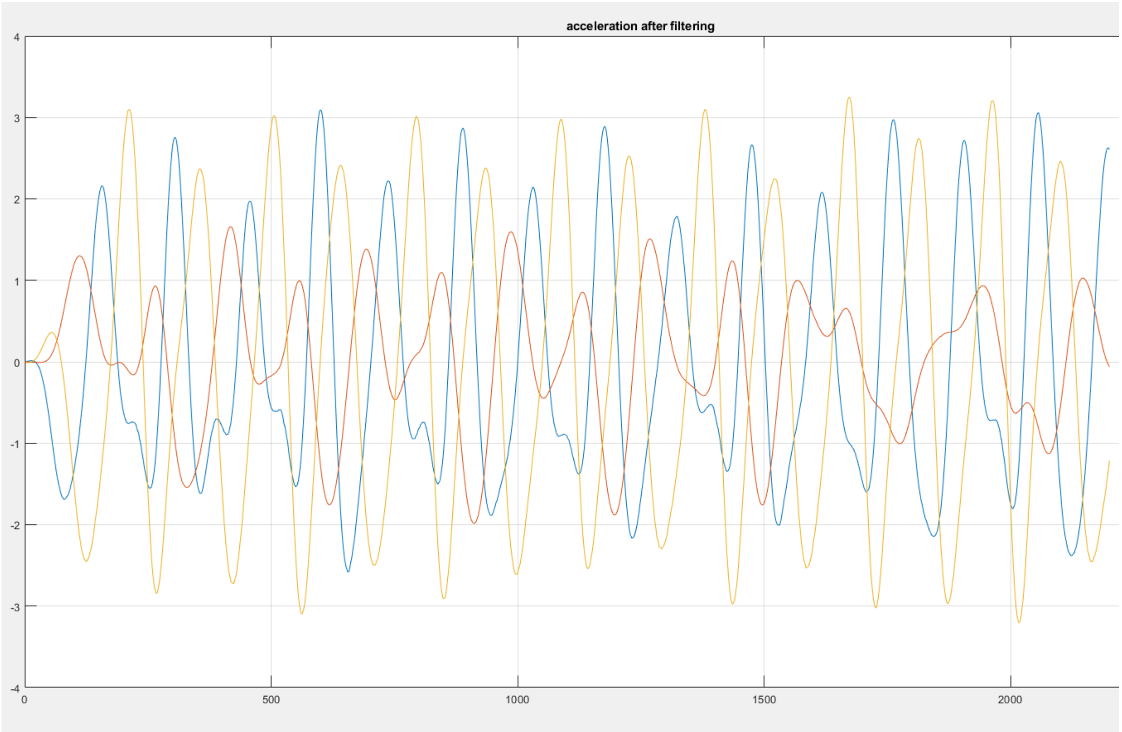


Figure 35. Slow trot filtered acceleration data for a non-professional rider

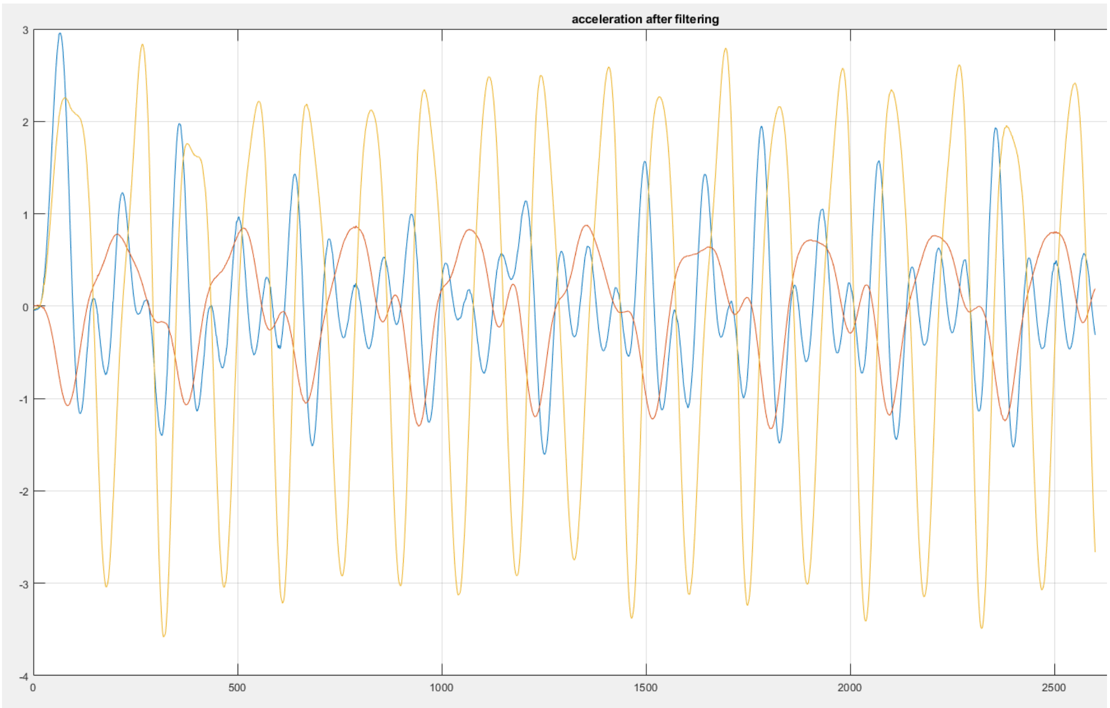


Figure 36. Slow trot filtered acceleration data for a professional rider

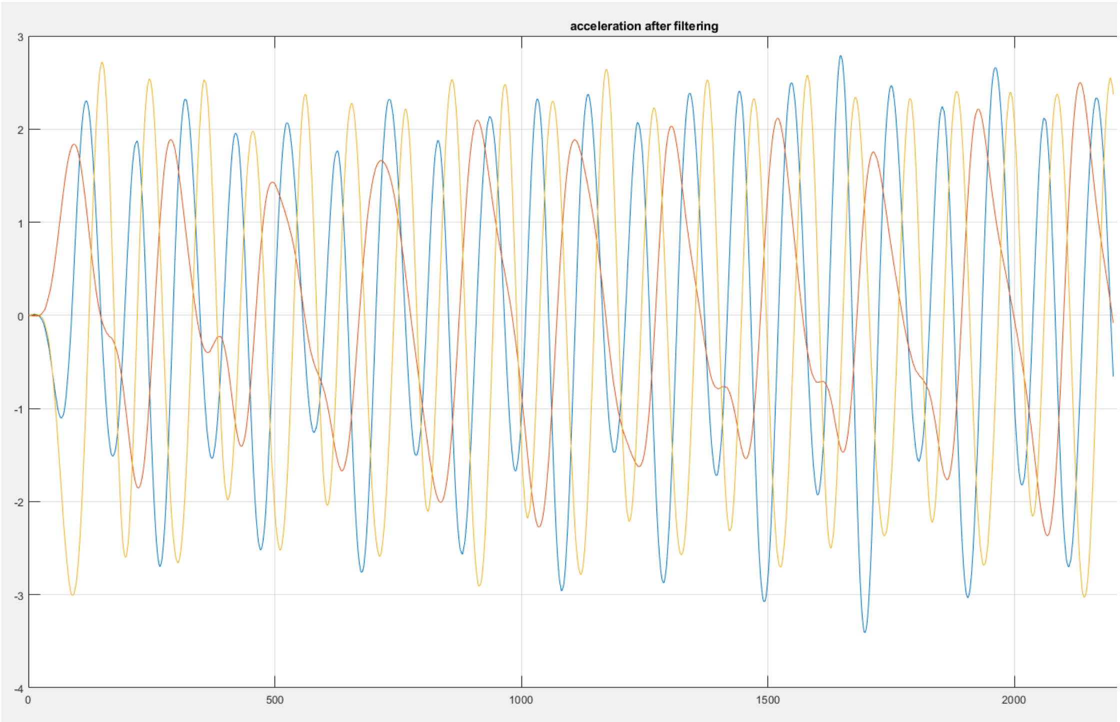


Figure 37. Fast trot filtered acceleration data for non-professional rider

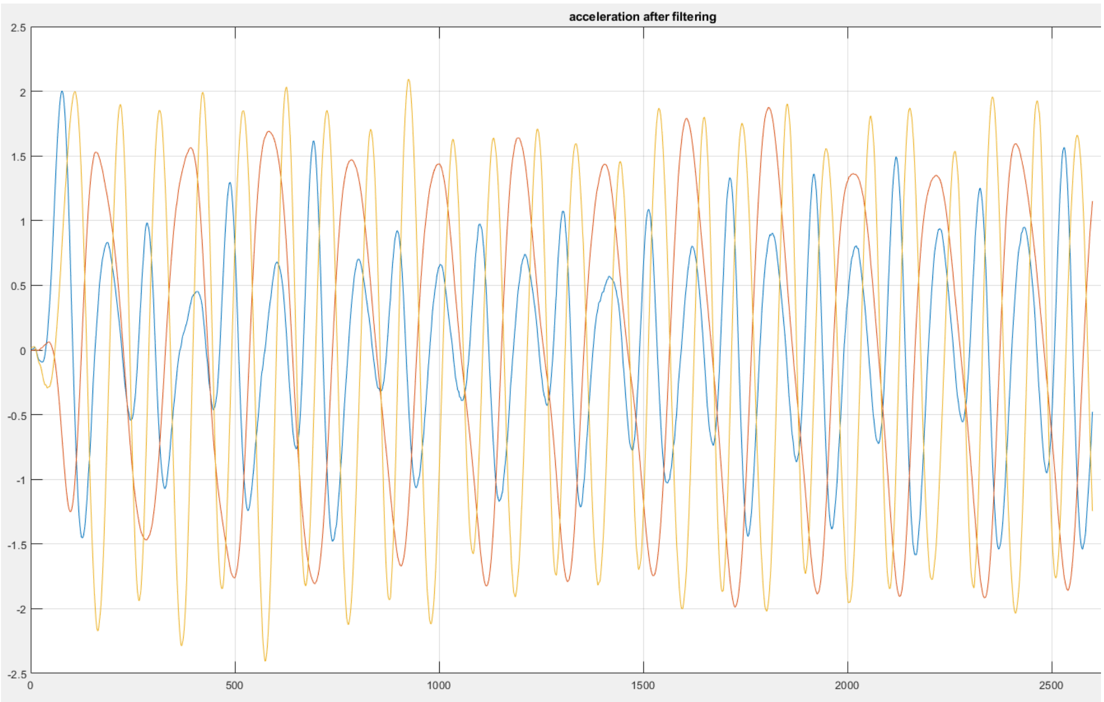


Figure 38. Fast trot filtered acceleration data for professional rider

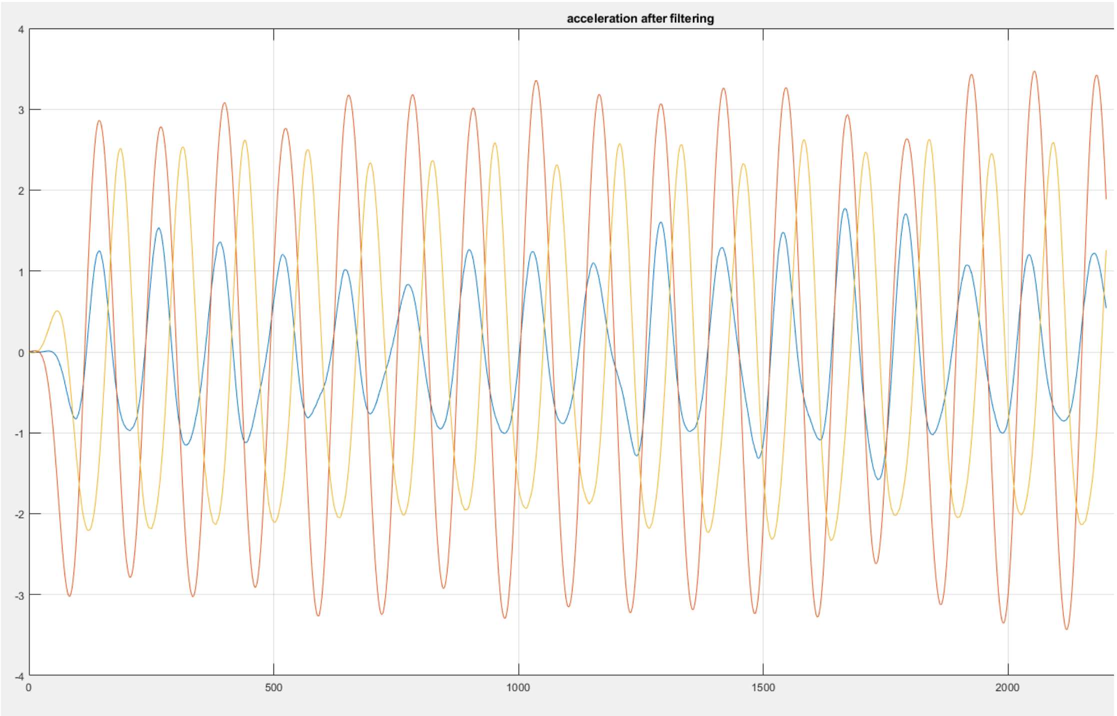


Figure 39. Slow gallop filtered acceleration data for non-professional rider

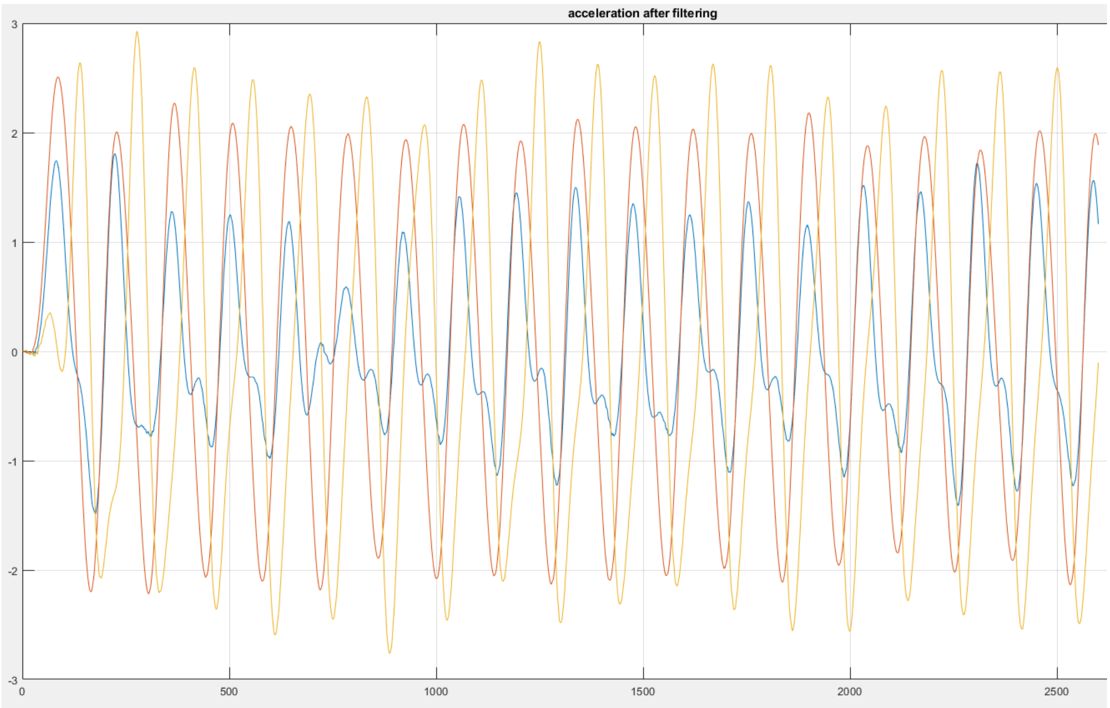


Figure 40. Slow gallop filtered acceleration data for professiaonal rider

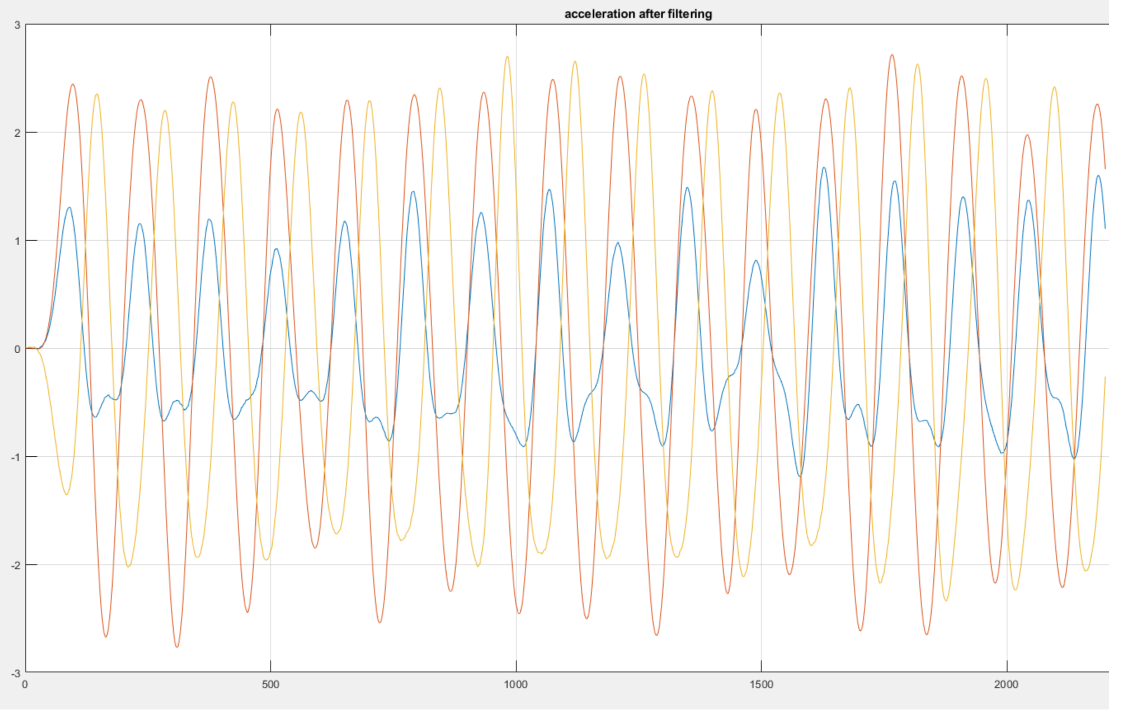


Figure 41. Fast gallop filtered acceleration data for non-professional rider

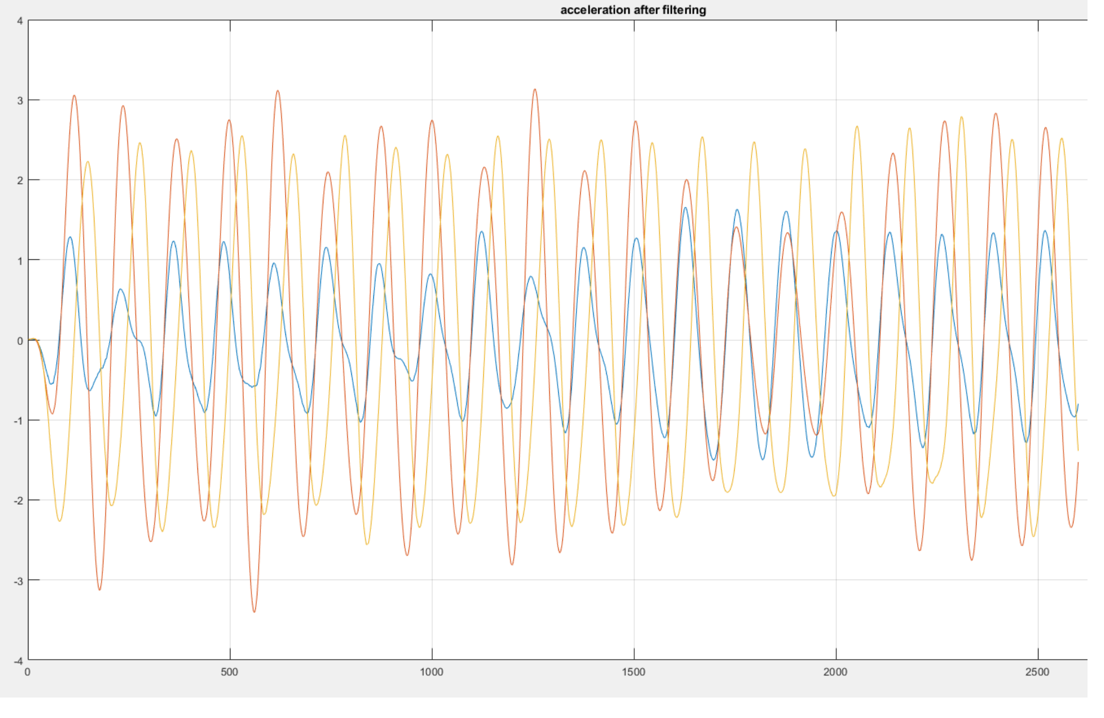


Figure 42. Fast gallop filtered acceleration data for professional rider

From the first look at the acceleration data graphs, it should be noted that graphs have a similar structure on a higher speed of all gaits including fast walk, trot and gallop. The amplitude of professional and non-professional riders is comparable. From a slow walk graph of a professional rider, it is seen that the amplitude of z-axis is higher. The reaction of a professional rider to horseback riding simulator movements is more accurate compared to the non-professional rider at the same gait. The acceleration of the pelvis of the professional rider changes on a smoother trajectory with lower amplitude compared to the non-professional rider. This is due to the fact that the professional rider has more experience in riding, knows how to find a correct position in the saddle and is able to maintain upright trunk position. On the next gait – a fast walk, it is obvious that non-professional rider feels more relaxed while riding compared to the first gait and his first ride, the professional rider controls horse’s movements, own body and understands how to behave due to the experienced background in riding. Observing the results of the slow and fast trot it is seen that the amplitude along the z-axis of the non-professional rider is higher and uneven, there is no sequence in movements. On fast trot, the curves of acceleration are more similar along the z-axis. On the slow gallop gait for the non-professional rider, there is too much displacement along the y-axis and almost no changes along the z-axis. While fast trot there is almost no differences along graphs as for non-professional rider it is easier to balance on the horse during a gallop, whereas this gait is similar to the running condition of the human. In addition, it may be caused by addictive to the horseback riding simulator’s movements.

The example of not filtered and filtered velocity data for slow walk gait of the horseback simulator for the non-professional and professional rider is shown on figures 43, 44 and figures 45, 46, respectively, where the x-axis is yellow, the y-axis is red, the z-axis is blue.

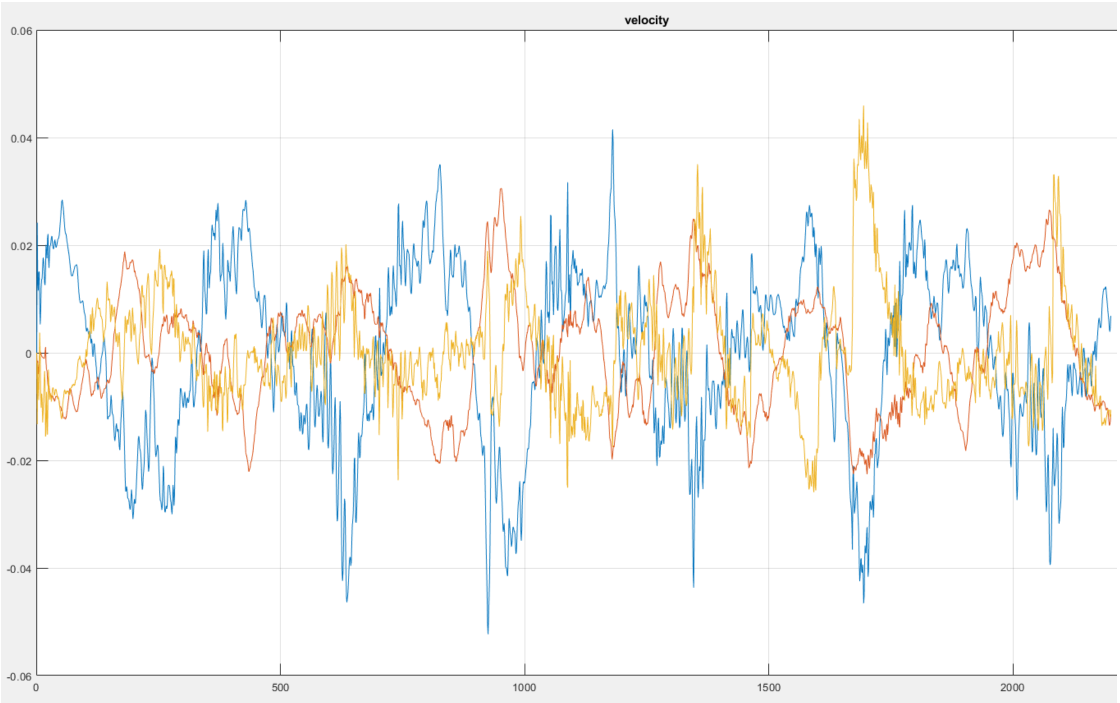


Figure 43. Slow walk not filtered velocity data for a non-professional rider

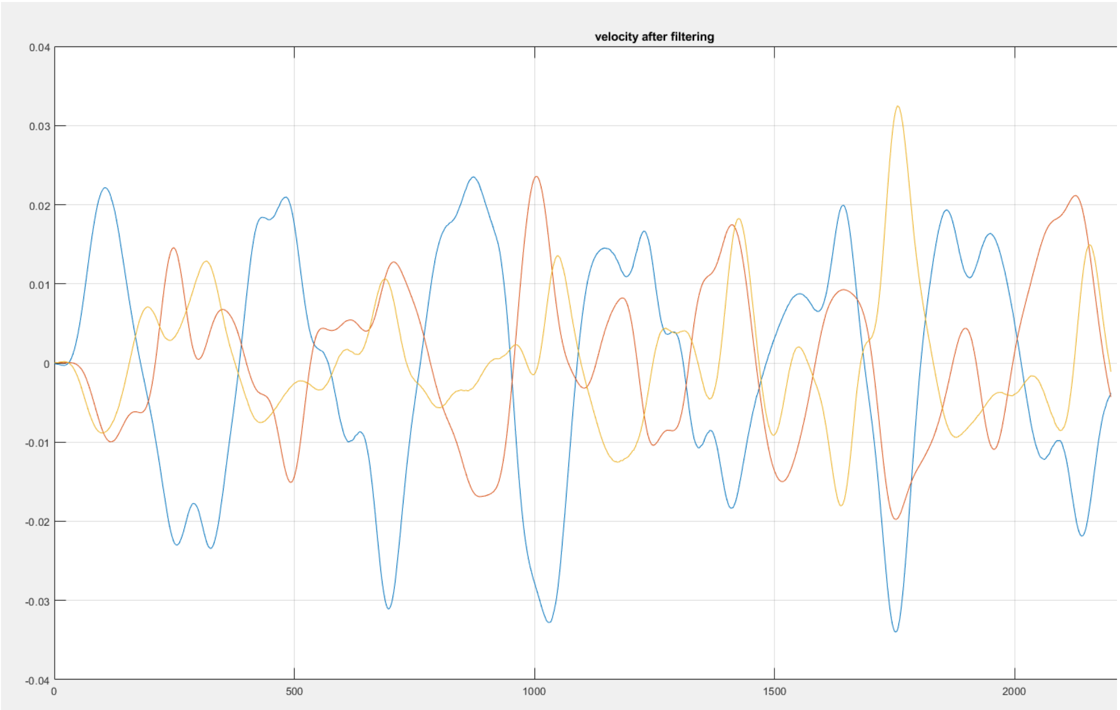


Figure 44. Slow walk filtered velocity data for a non-professional rider

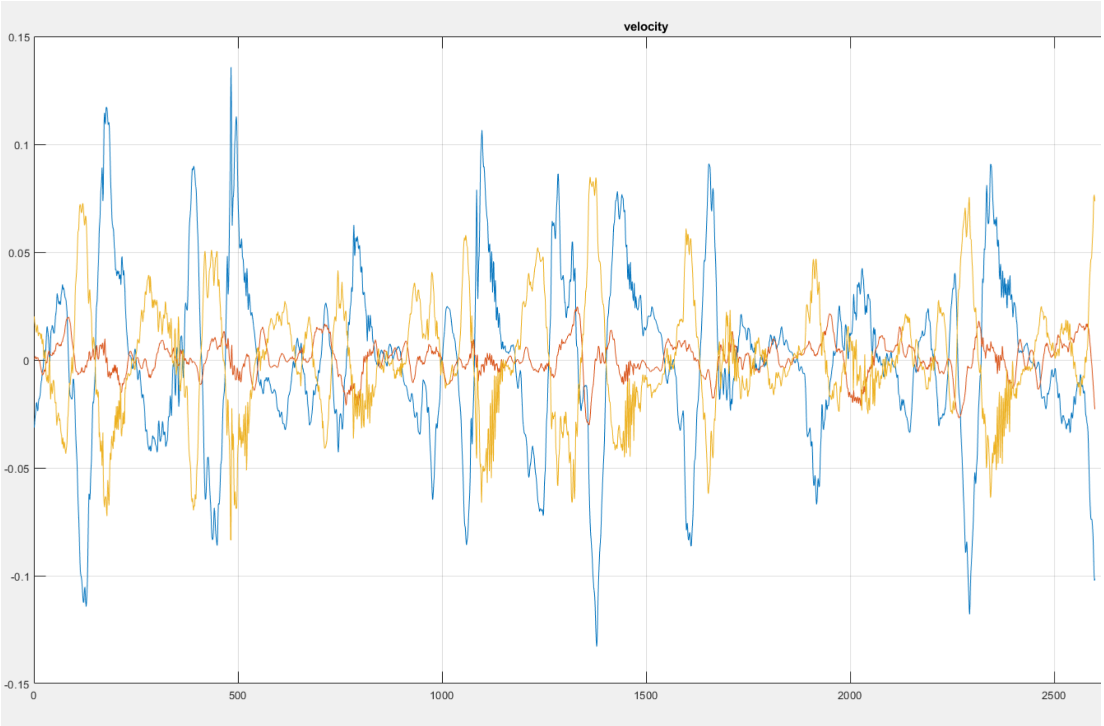


Figure 45. Slow walk not filtered velocity data for a professional rider

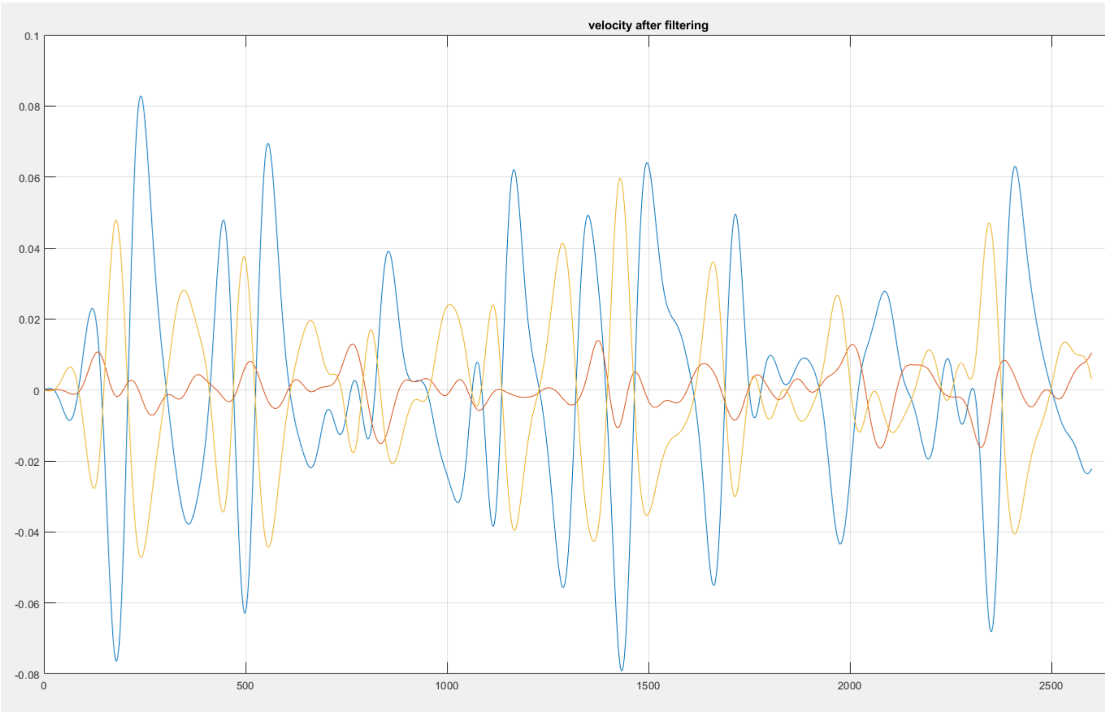


Figure 46. Slow walk filtered velocity data for a professional rider

Filtered velocity data for the rest of gaits such as fast walk, slow and fast trot, slow and fast gallop for the non-professional and professional rider, respectively, is shown on figures 47-56 below.

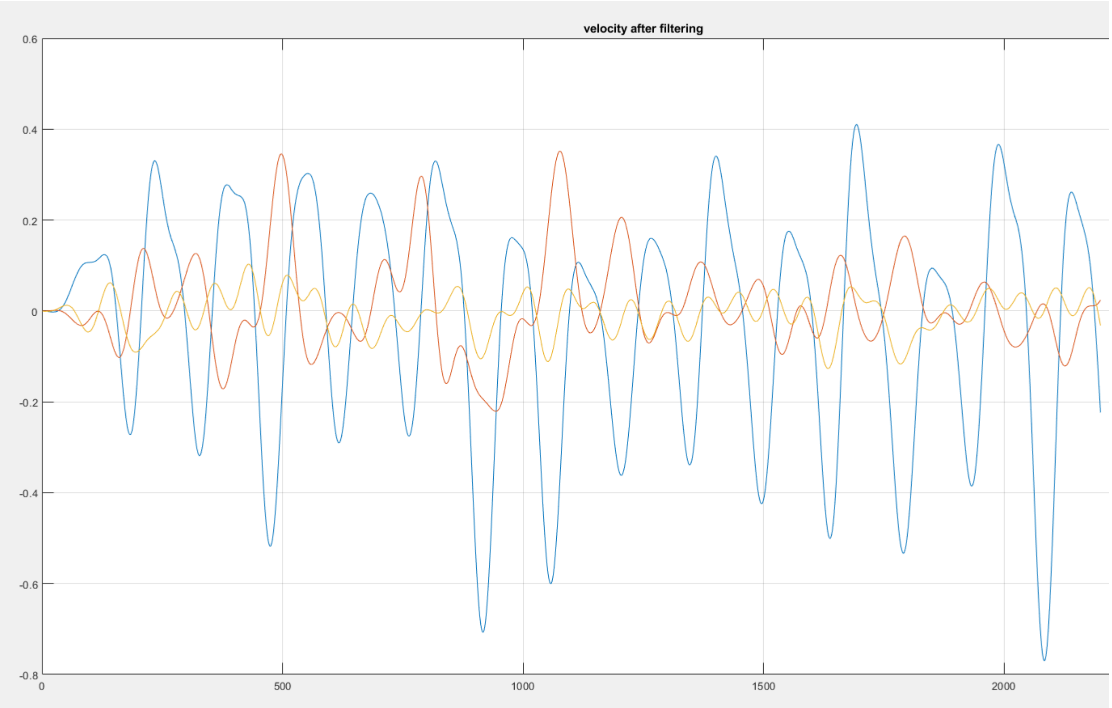


Figure 47. Fast walk filtered velocity data for a non-professional rider

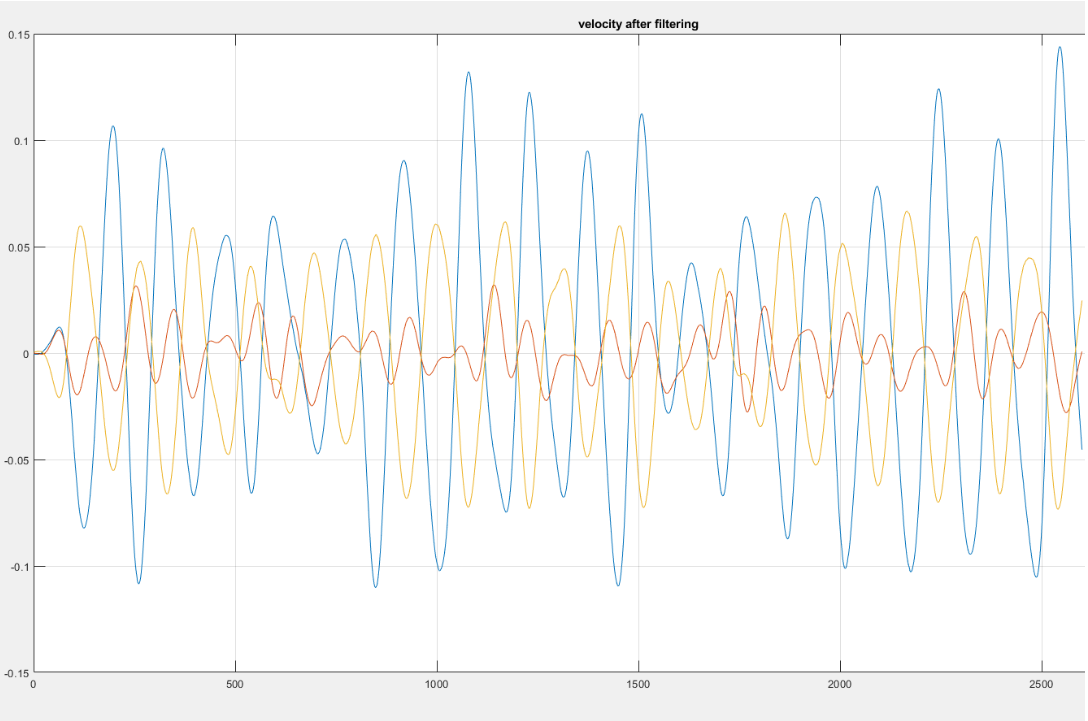


Figure 48. Fast walk filtered velocity data for a professional rider

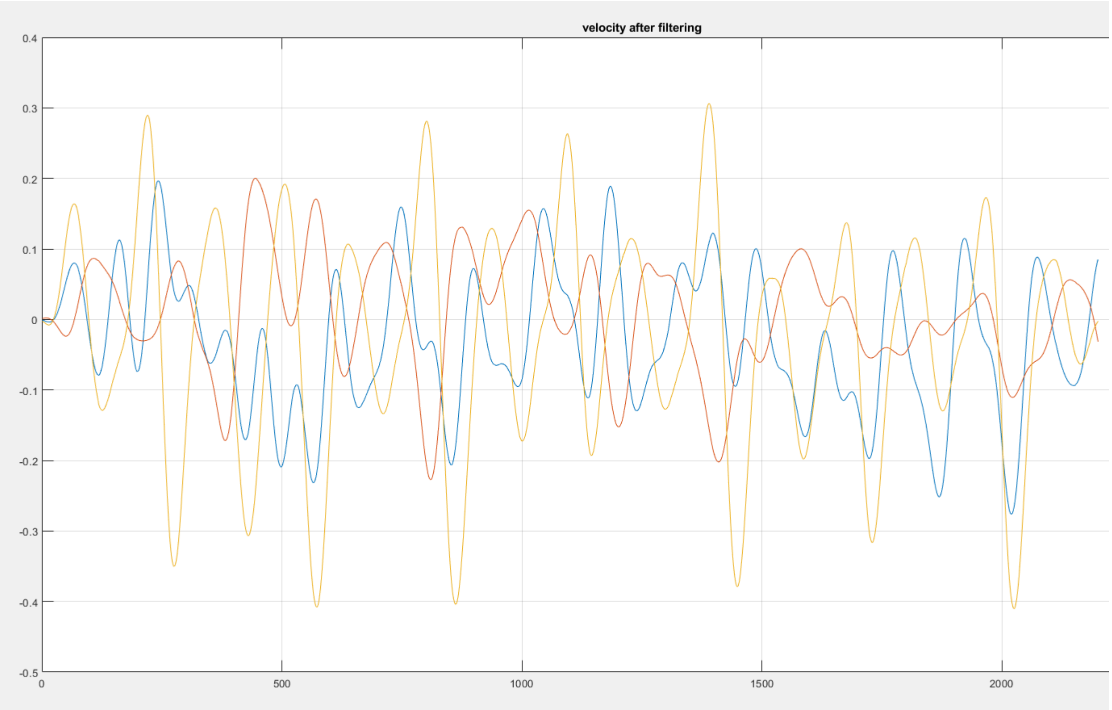


Figure 49. Slow trot filtered velocity data for a non-professional rider

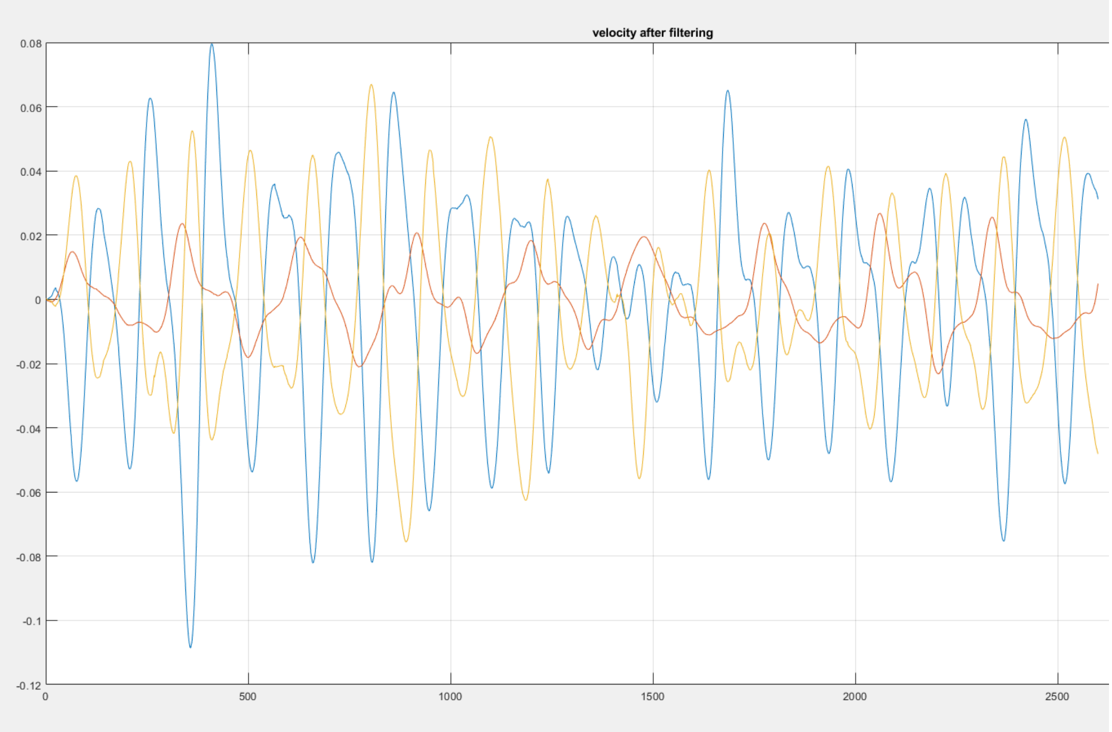


Figure 50. Slow trot filtered velocity data for a professional rider

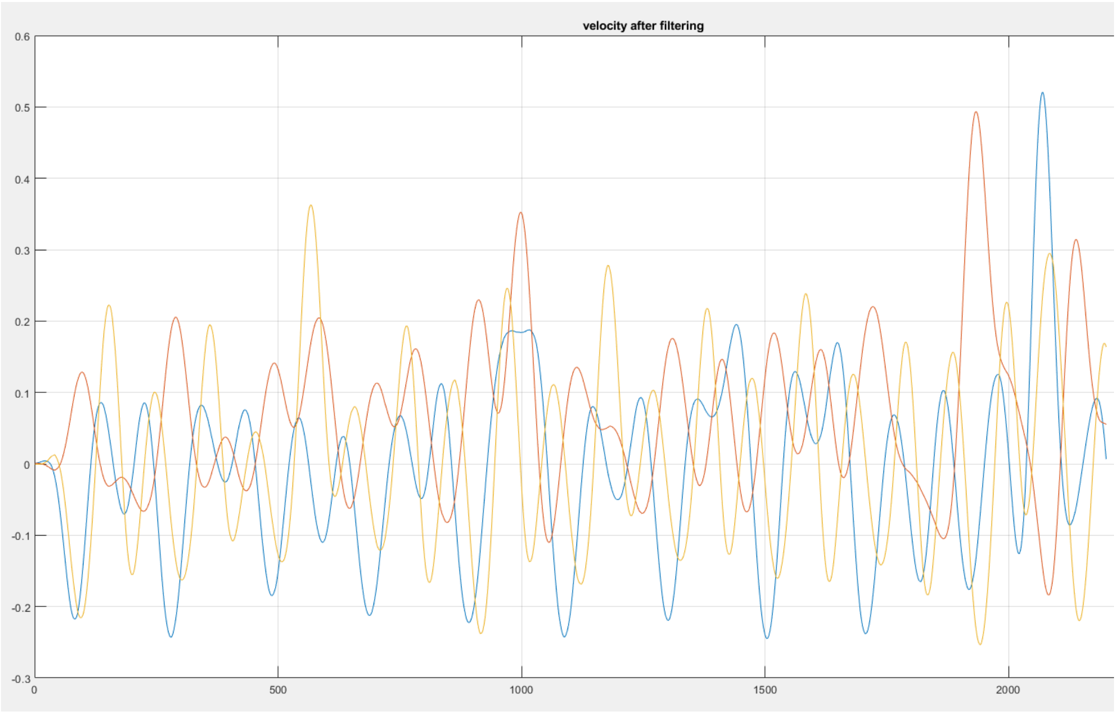


Figure 51. Fast trot filtered velocity data for a non-professional rider

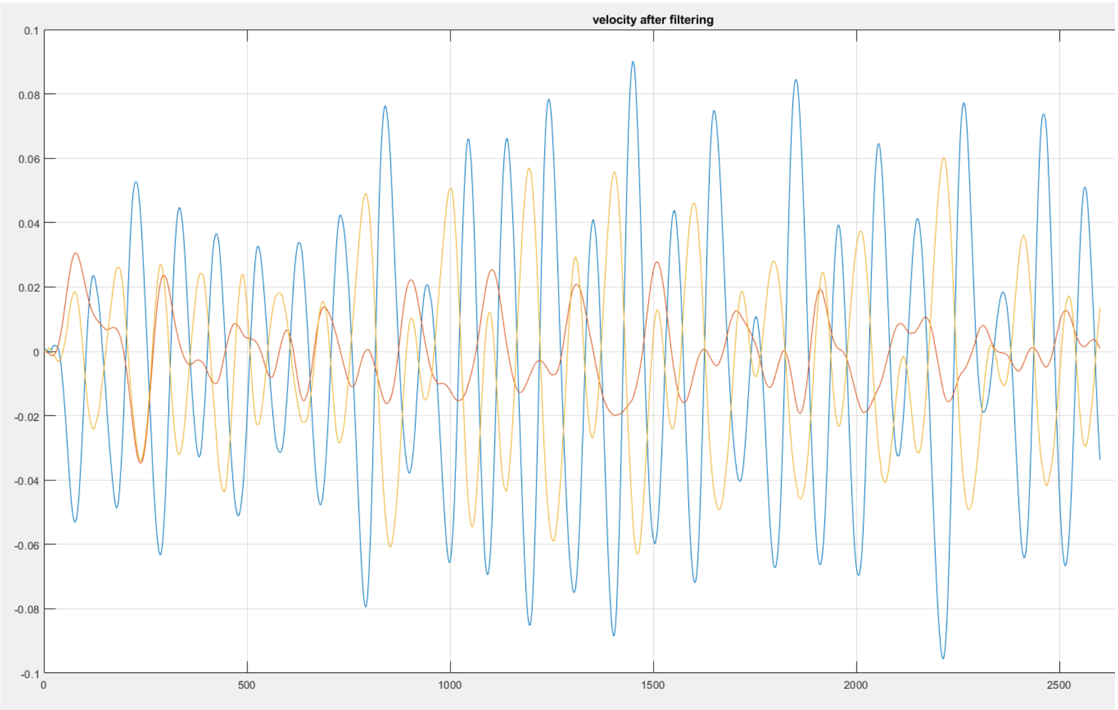


Figure 52. Fast trot filtered velocity data for a professional rider

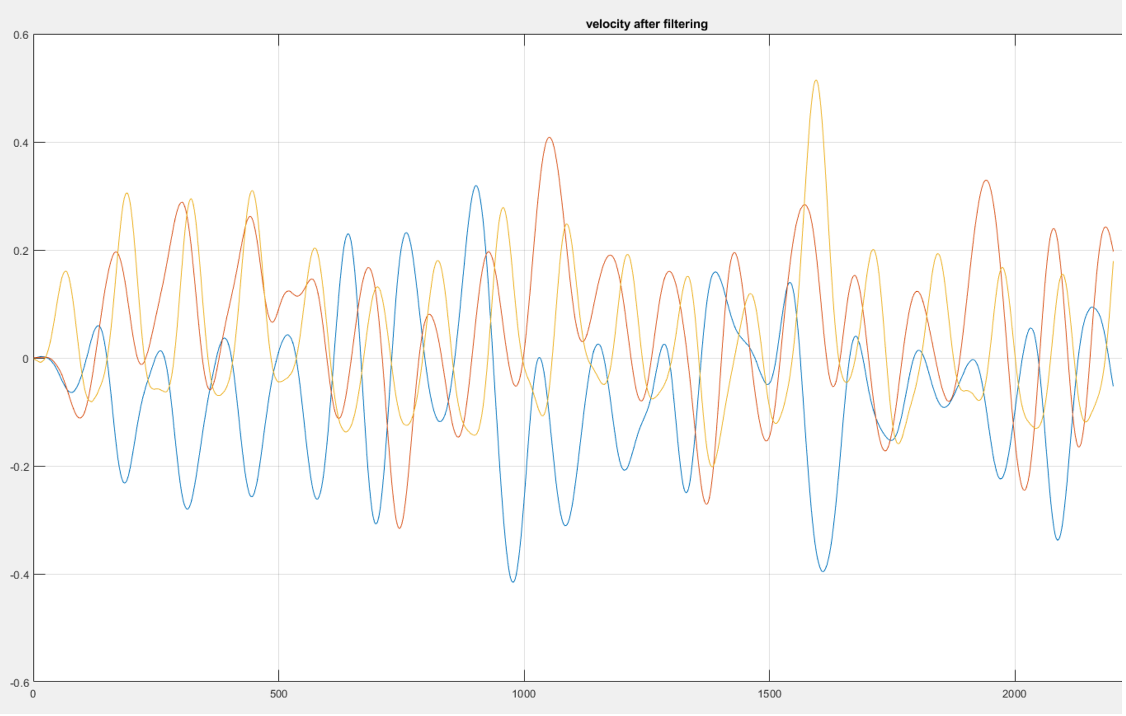


Figure 53. Slow gallop filtered velocity data for a non-professional rider

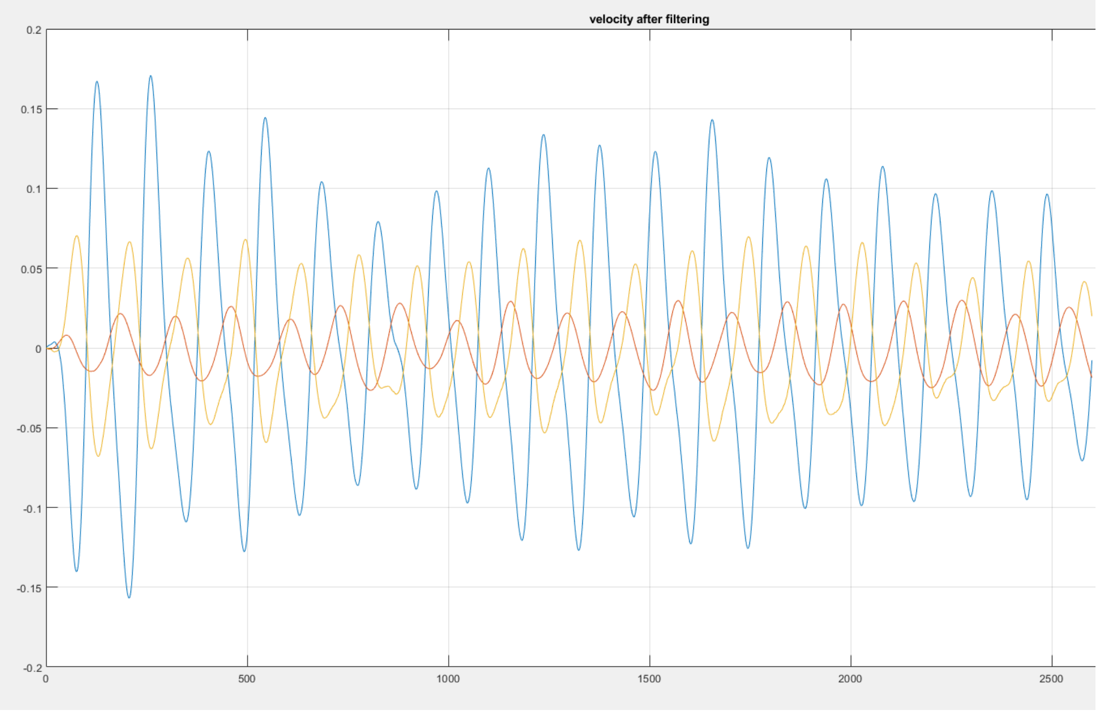


Figure 54. Slow gallop filtered velocity data for a professional rider

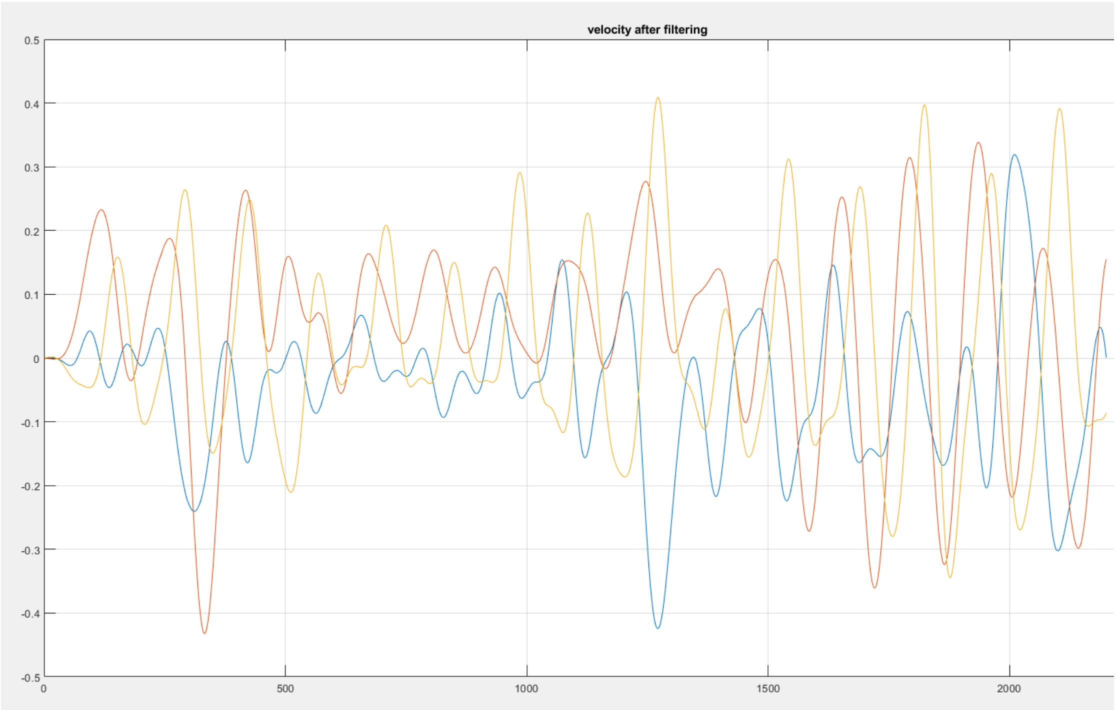


Figure 55. Fast gallop filtered velocity data for a non-professional rider

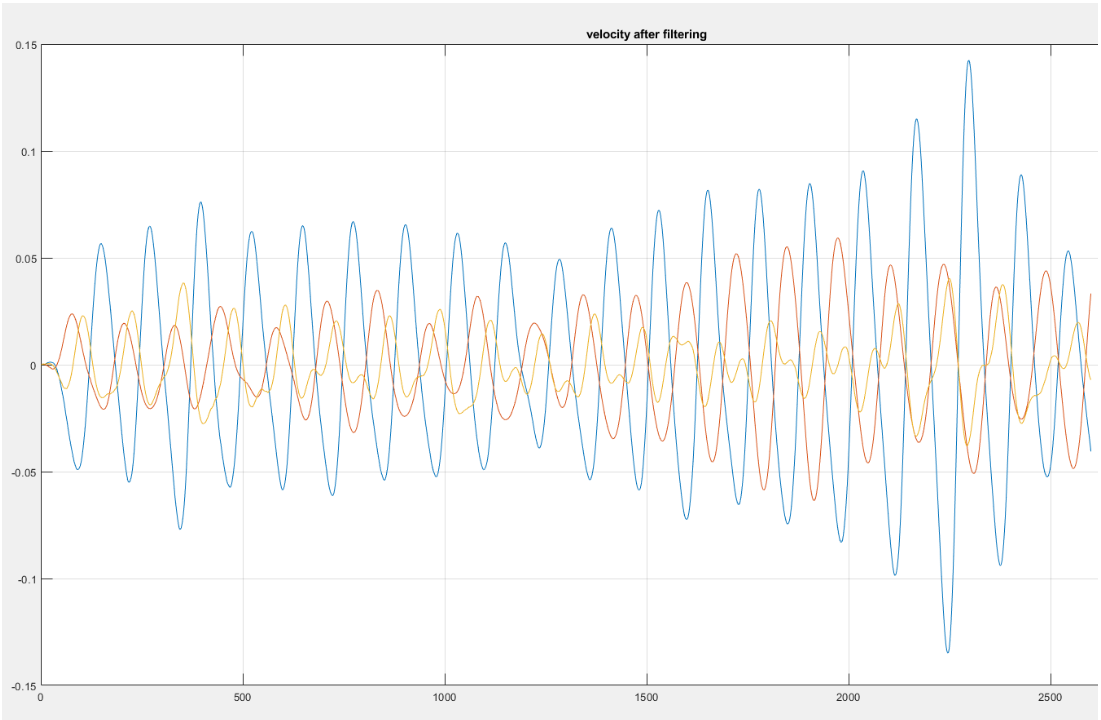


Figure 56. Fast gallop filtered velocity data for professional rider

From the cursory look of the results, first, that catches the eye is that all velocity data for non-professional and professional riders are different. Comparable amplitude can be noted only at slow and fast walk gait. At slow and fast walk gait it is seen that professional rider velocity synchronizes with horseback simulator's velocity and movements with every step. Velocity data of non-professional rider has chaotic behaviour at every mode of horseback riding simulator, especially, at the slow and fast walk and slow trot. From slow trot mode amplitude of non-professional rider starts to change from the z-axis to the x-axis and increases with every following mode of the simulator. At a fast trot, the amplitude of the velocity data on the figure has the most chaotic behaviour along the x-axis. Besides, at slow and fast trot amplitude changes randomly along three axes without any tendency. At slow and fast gallop there is a similar pattern for velocity data of the non-professional rider riding horseback simulator. Velocity data of the professional rider can be distinguished from the velocity data of non-professional rider easily. Due to the fact that, it is readable, understandable and does not have a disorderly character at all gaits, including slow and fast trot and gallop. Moreover, the amplitude of the professional rider changes only along one z-axis throughout time.

The example of not filtered and filtered angular velocity data for slow walk gait of the horseback simulator for the non-professional and professional rider is shown on figures 57, 58 and figures 59, 60, respectively, where the x-axis is yellow, the y-axis is red, the z-axis is blue.

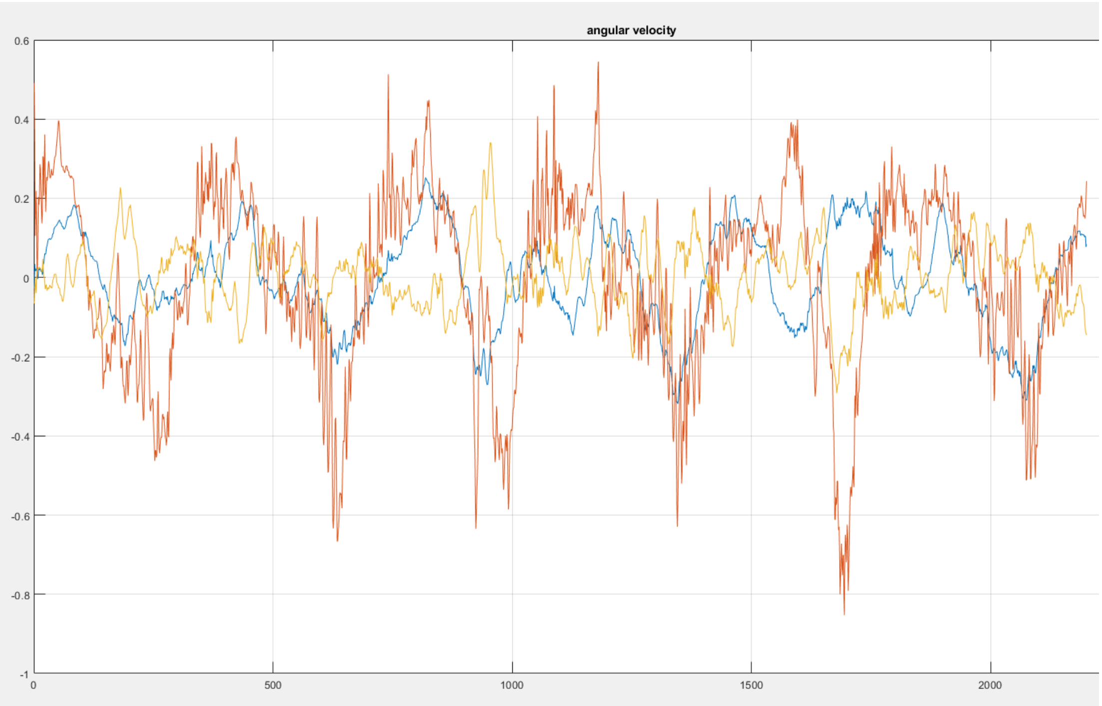


Figure 57. Slow walk not filtered angular velocity data for a non-professional rider

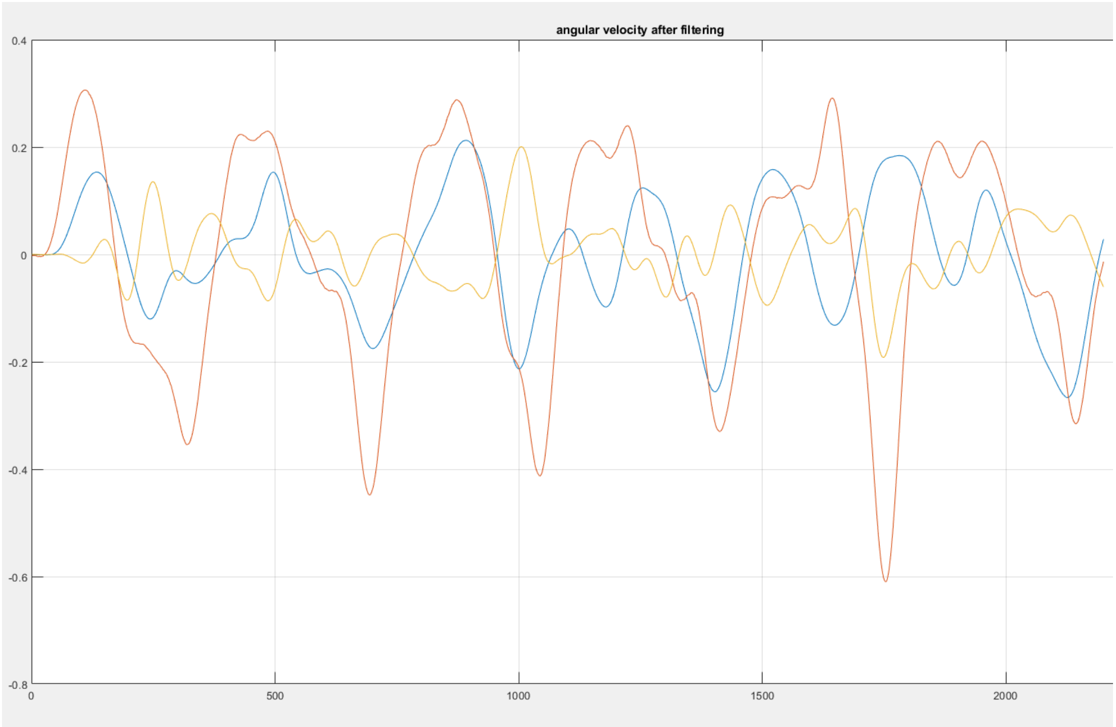


Figure 58. Slow walk filtered angular velocity data for a non-professional rider

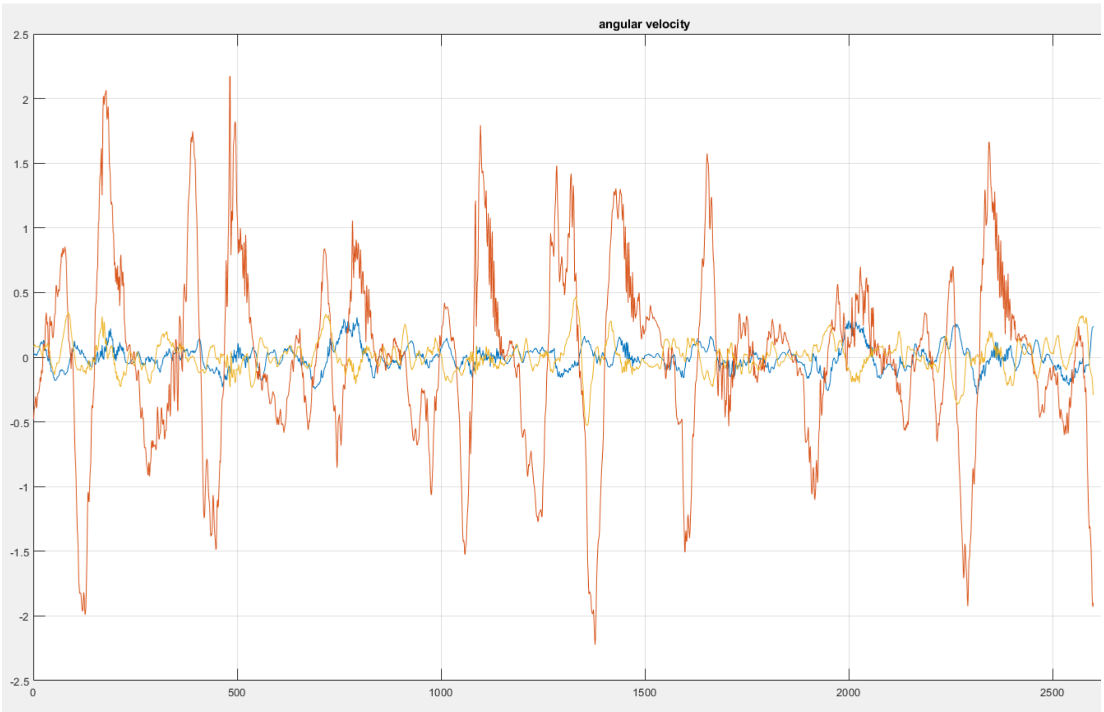


Figure 59. Slow walk not filtered angular velocity data for a professional rider

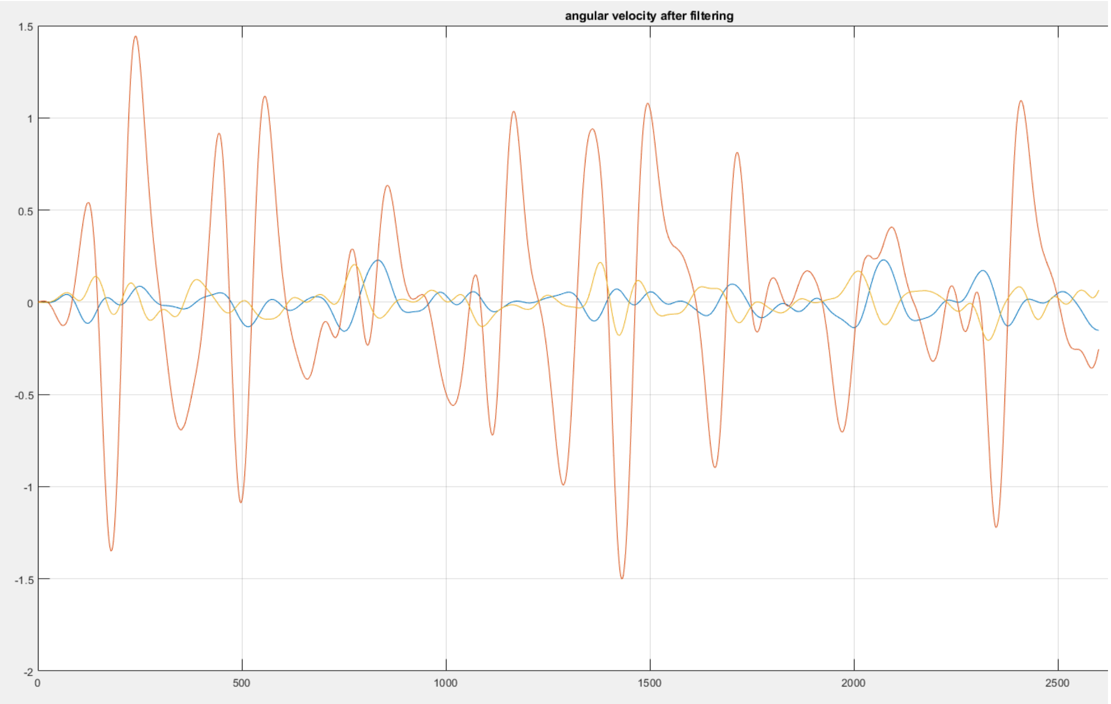


Figure 60. Slow walk filtered angular velocity data for a professional rider

Filtered angular velocity data for the rest of gaits such as fast walk, slow and fast trot, slow and fast gallop for the non-professional and professional rider, respectively, is shown on figures 61-70 below.

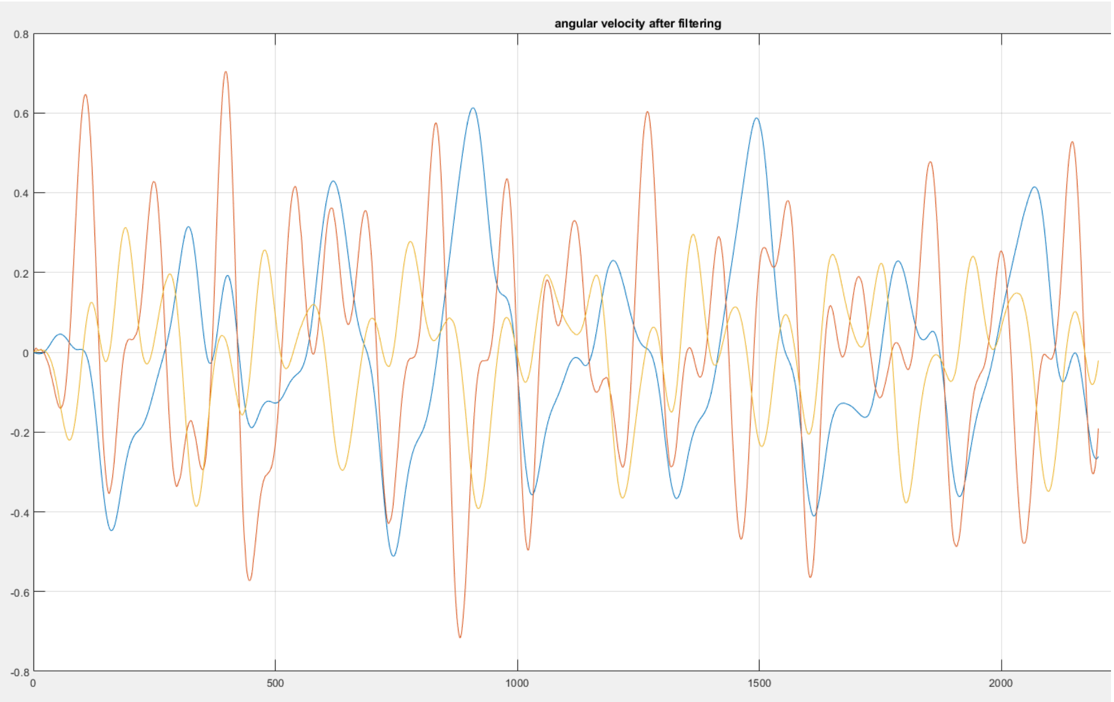


Figure 61. Fast walk filtered angular velocity data for a non-professional rider

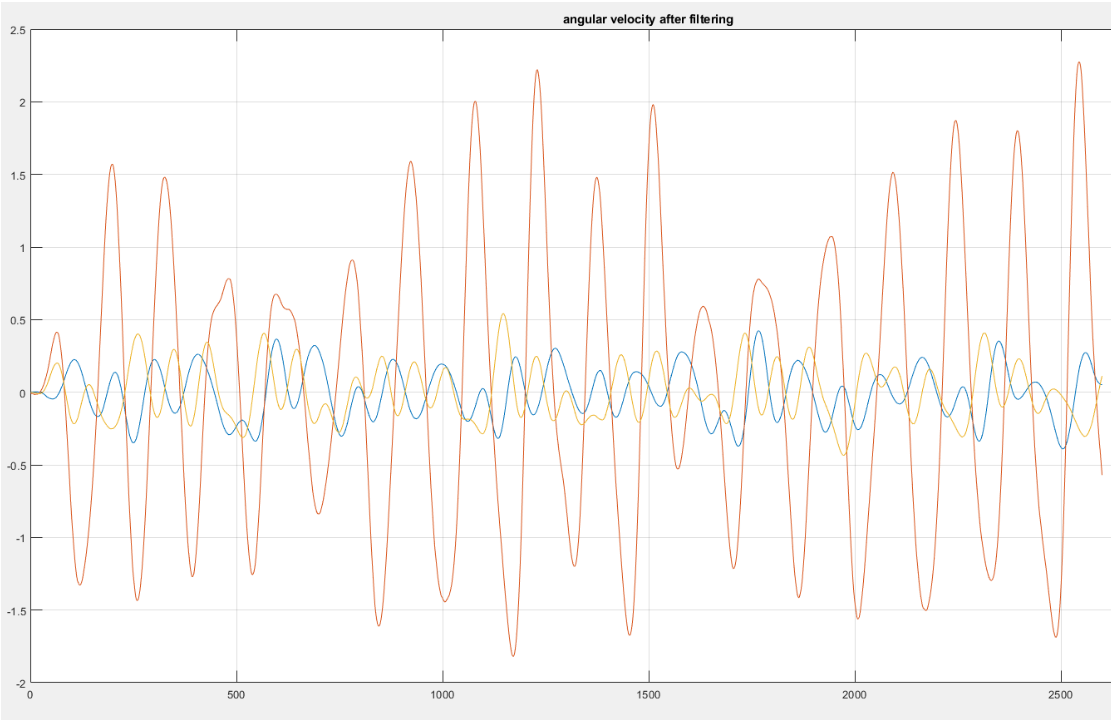


Figure 62. Fast walk filtered angular velocity data for a professional rider

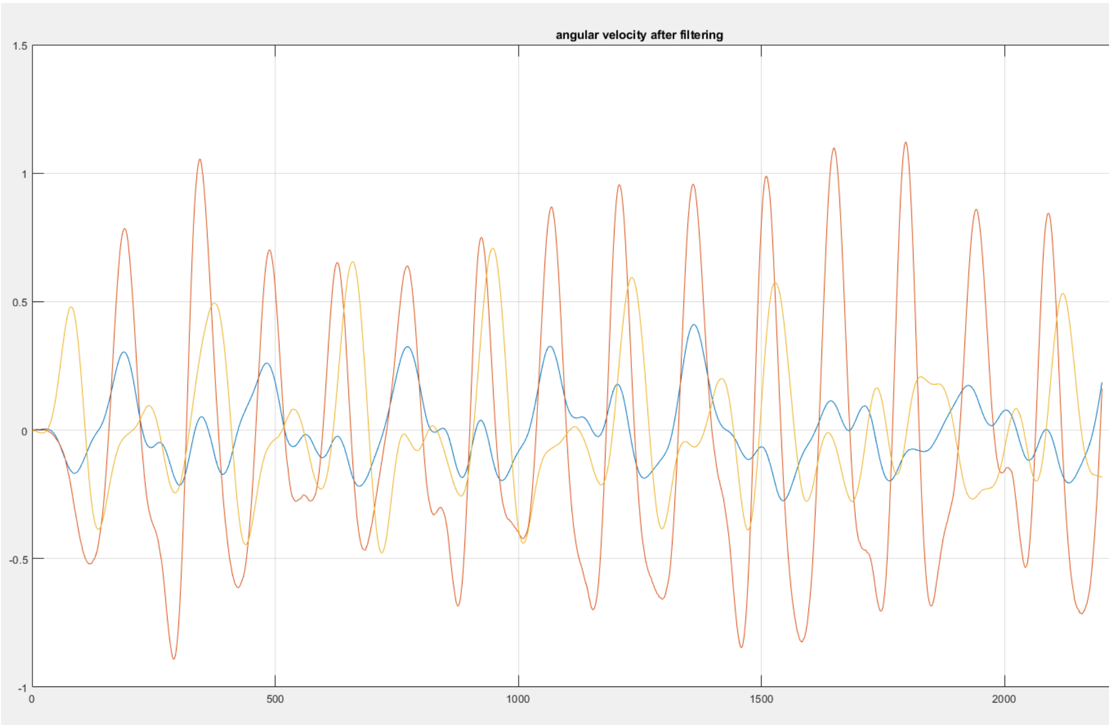


Figure 63. Slow trot filtered angular velocity data for a non-professional rider

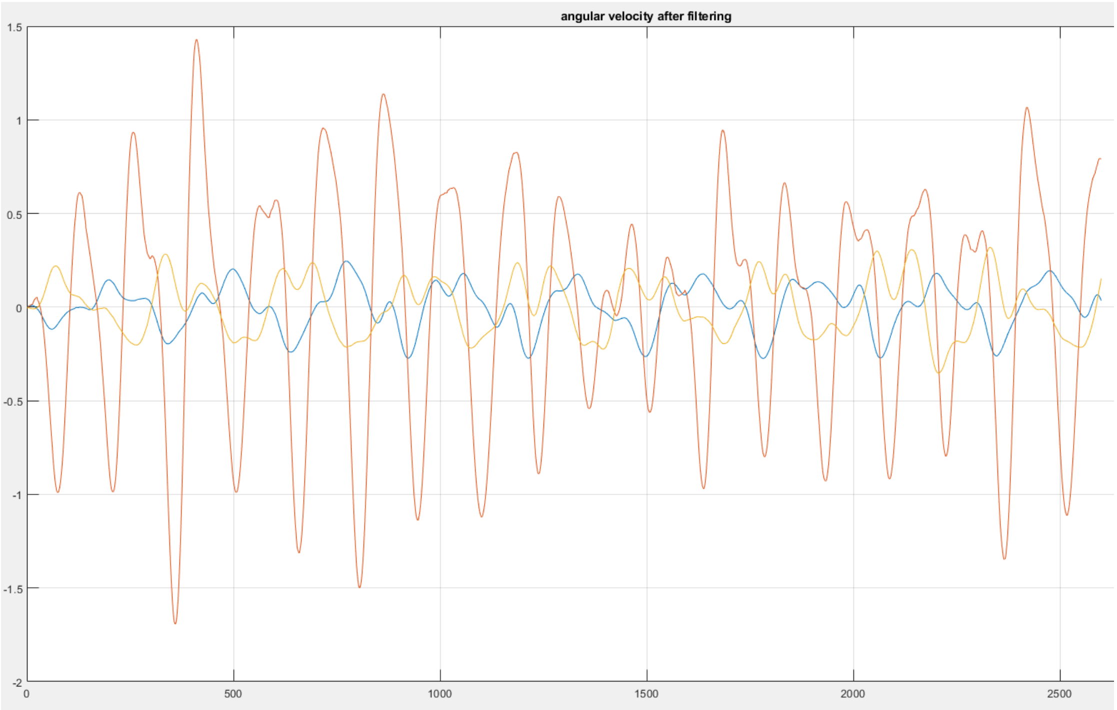


Figure 64. Slow trot filtered angular velocity data for a professional rider

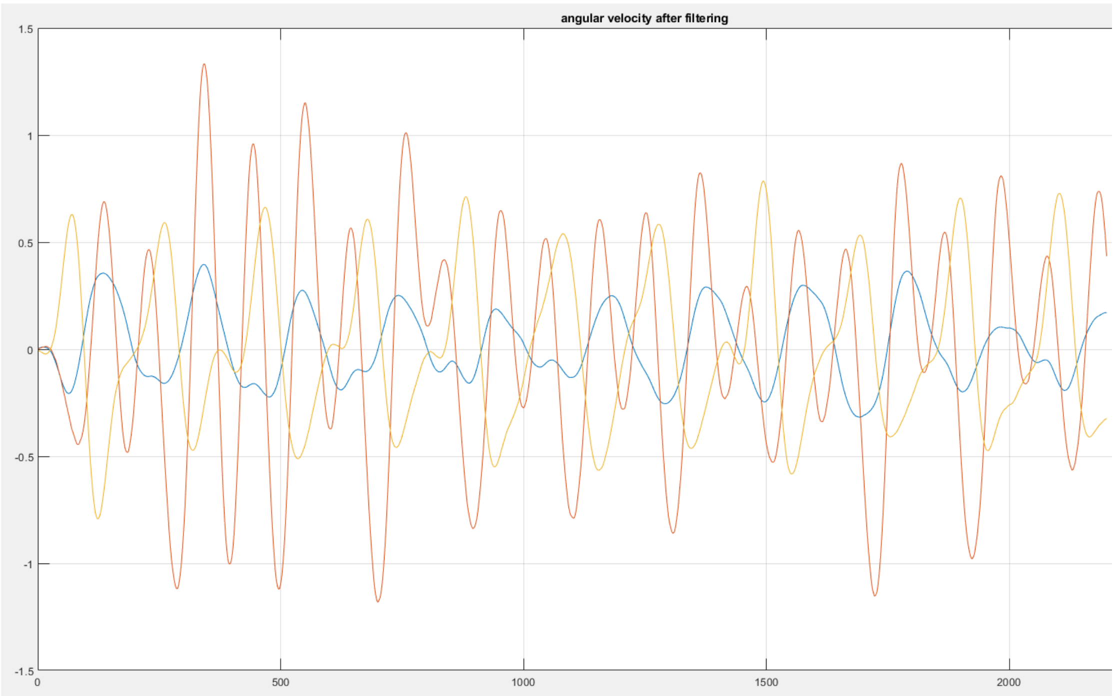


Figure 65. Fast trot filtered angular velocity data for a non-professional rider

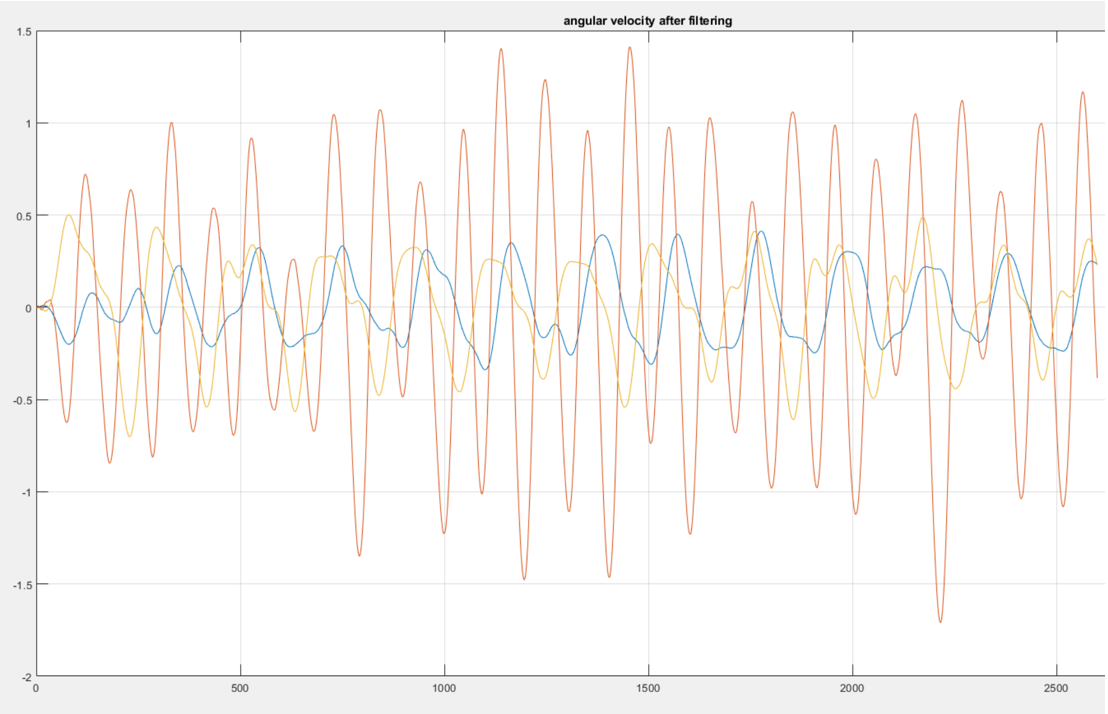


Figure 66. Fast trot filtered angular velocity data for a professional rider

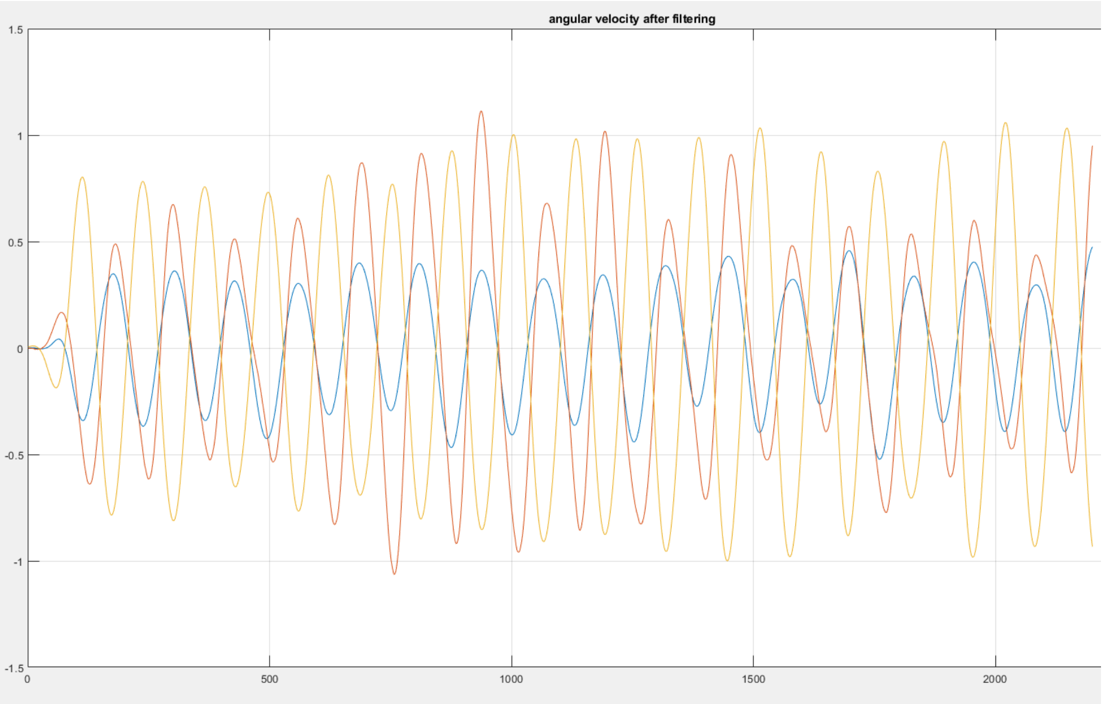


Figure 67. Slow gallop filtered angular velocity data for a non-professional rider

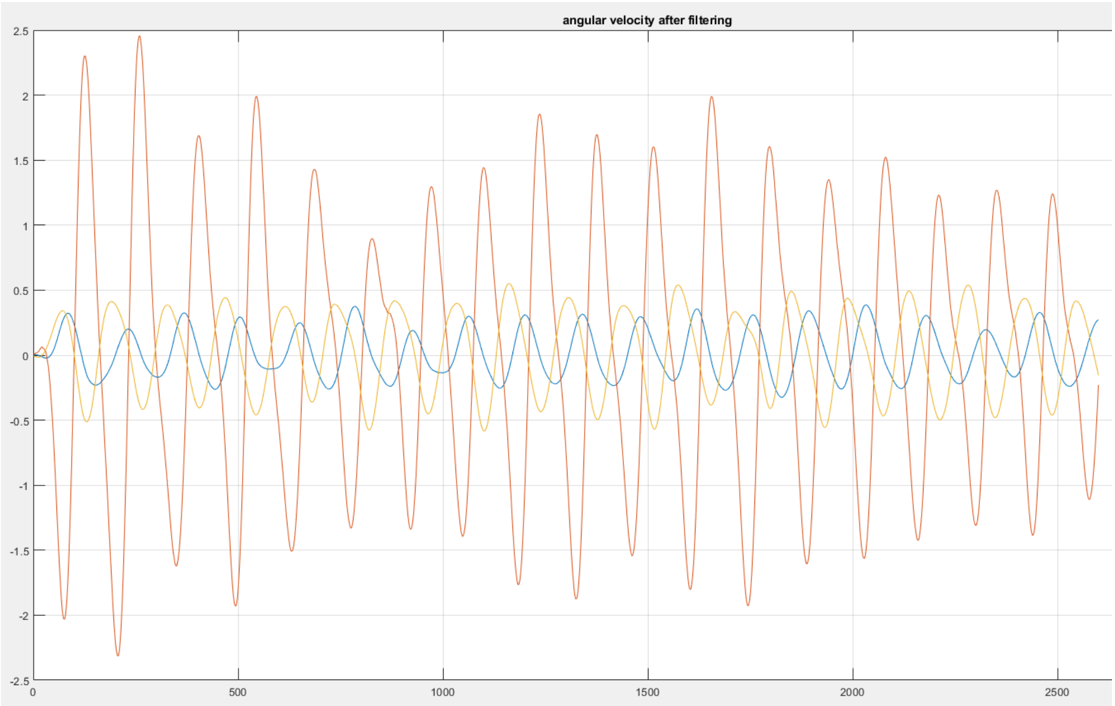


Figure 68. Slow gallop filtered angular velocity data for a professional rider

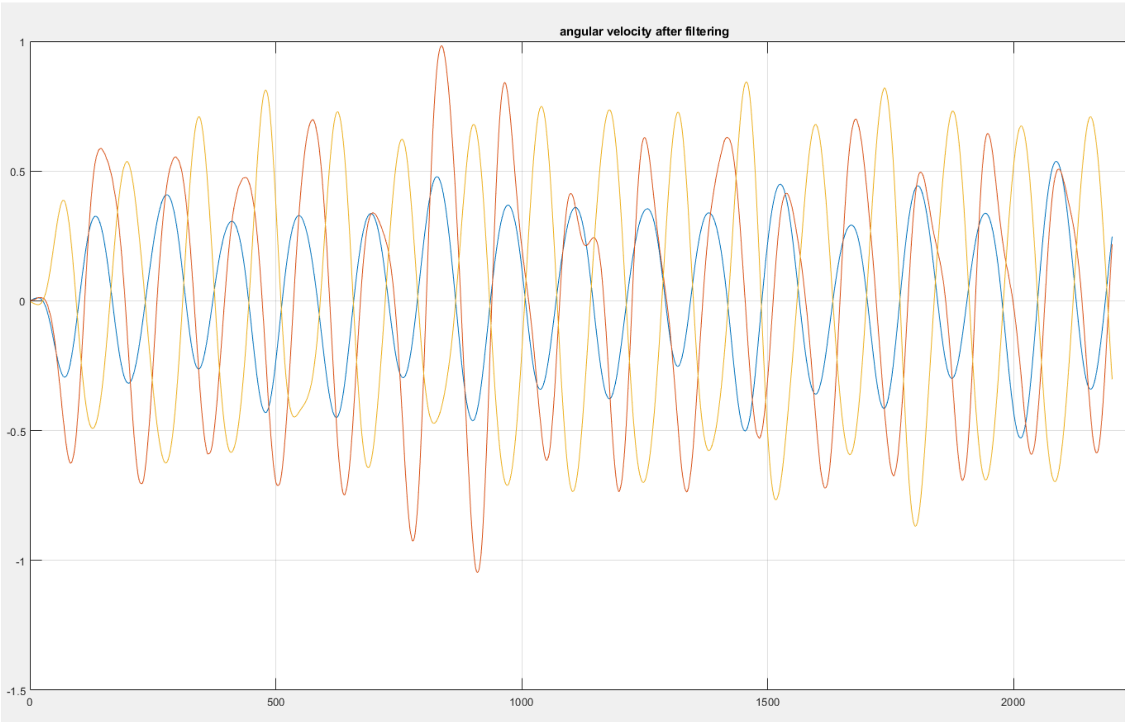


Figure 69. Fast gallop filtered angular velocity data for a non-professional rider

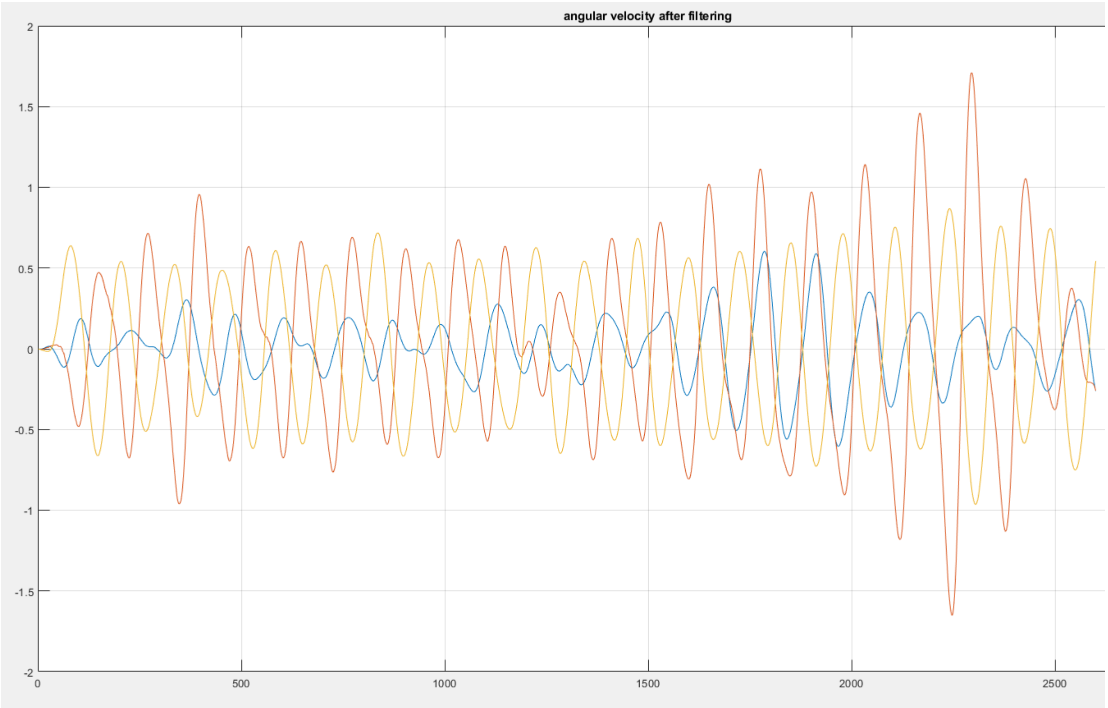


Figure 70. Fast gallop filtered angular velocity data for a professional rider

Analyzing given angular velocity data of professional and non-professional rider utilizing horseback simulator it should be mentioned that at slow walk gait the amplitude changing is equal along each axis although with the disorder and there is a similarity with horse's movements and steps. Higher amplitude of a professional rider traces along the y-axis, changes along other axes are minimal, what is caused by the meaning, description and physical properties of angular velocity. At the fast walk, there is the same trend for the rider as the previous gait, but the amplitude of the non-professional rider increases and the amplitude of z-axis is extremely different from other cases. In other respects, changes along the z-axis of professional and non-professional riders are comparable. At the slow and fast trot, the amplitude along y-axis increases, that makes the scenario of angular velocity data graphs more similar with a professional rider. At a slow gallop, the amplitude rises along x- and y-axes for non-professional rider and only along y-axes for the professional rider that can be explained by the level of experience of the riders. At a slow gallop, the amplitude rises along x- and y-axes for both non-professional and professional riders that can be explained that when a person experiences the fast gallop gait then the perception of force given from the horse is similar to the running condition for the human body.

The data for position and orientation does not need to be filtered. Therefore, normalized into the equal time strides for each parameter. For the professional rider, time strides account 2600 points and for the non-professional rider, time strides account 2200 points. The graphs were obtained using Xsens MVN Studio software, where the x-axis is red, the y-axis is green, the z-axis is blue. Position data for the gaits such as slow and fast walk, trot, and gallop for the non-professional and professional rider, respectively, are shown on figures 71-82 below.

Figure 71. Slow walk position data for a non-professional rider

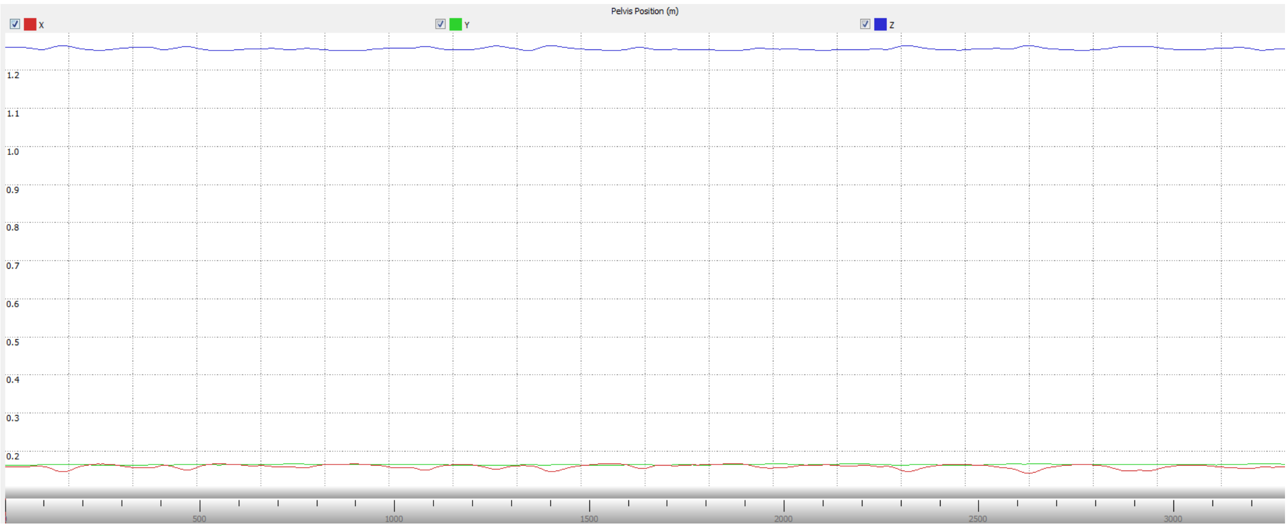


Figure 72. Slow walk position data for a professional rider

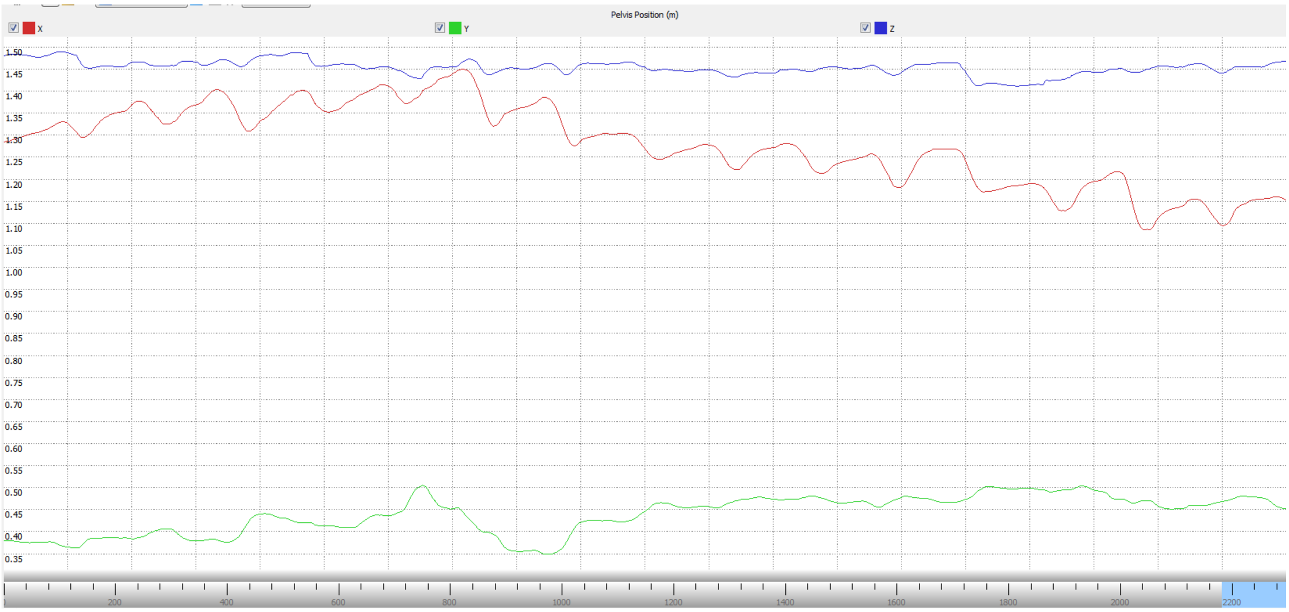


Figure 73. Fast walk position data for a non-professional rider

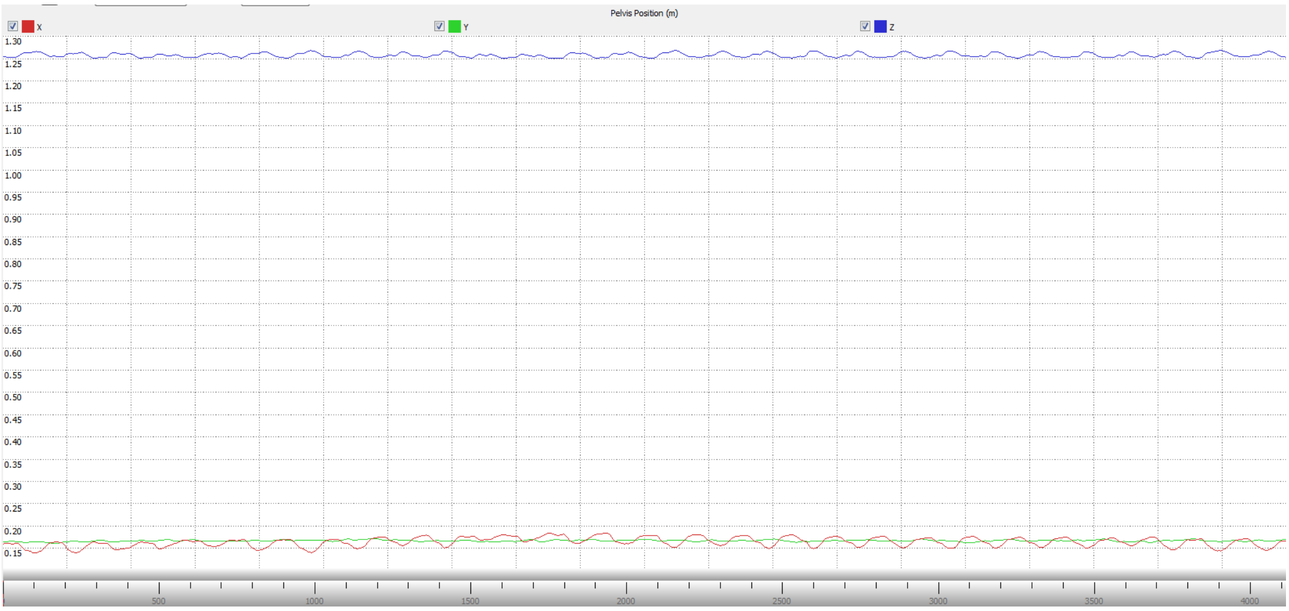


Figure 74. Fast walk position data for a professional rider

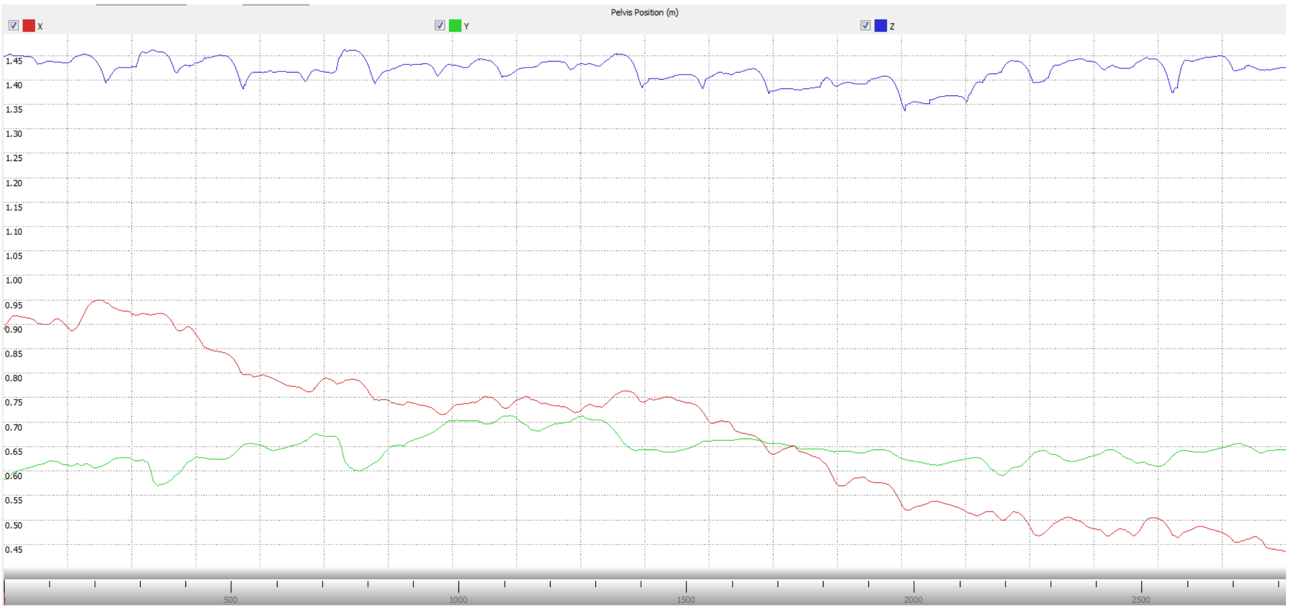


Figure 75. Slow trot position data for a non-professional rider

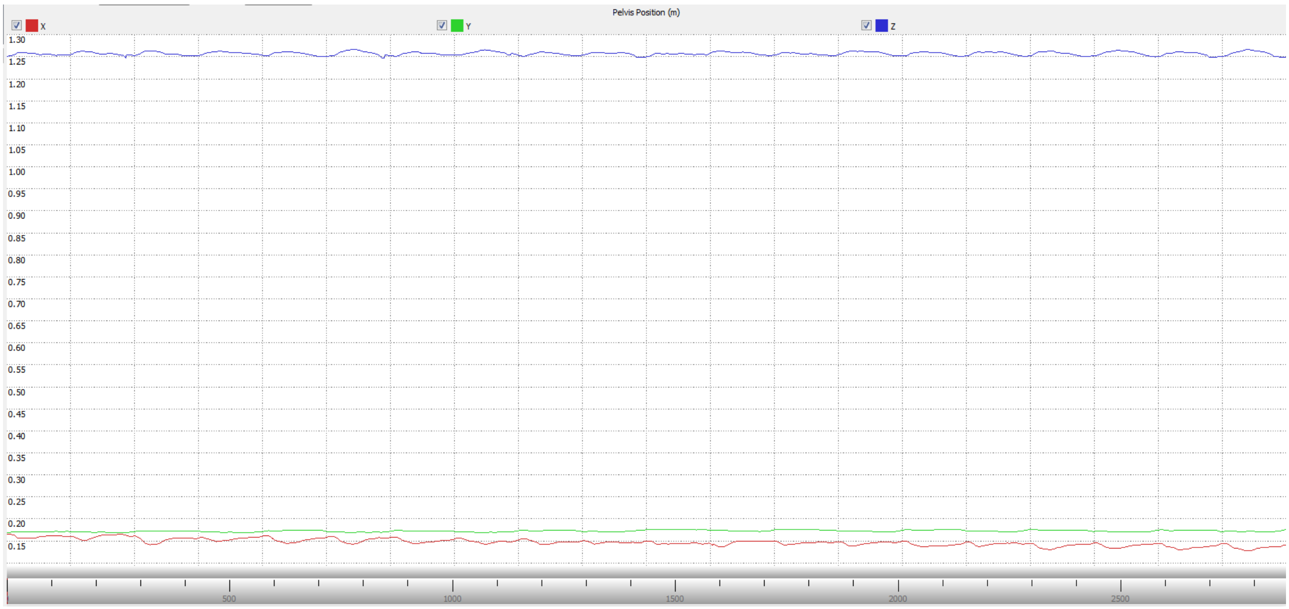


Figure 76. Slow trot position data for professional rider

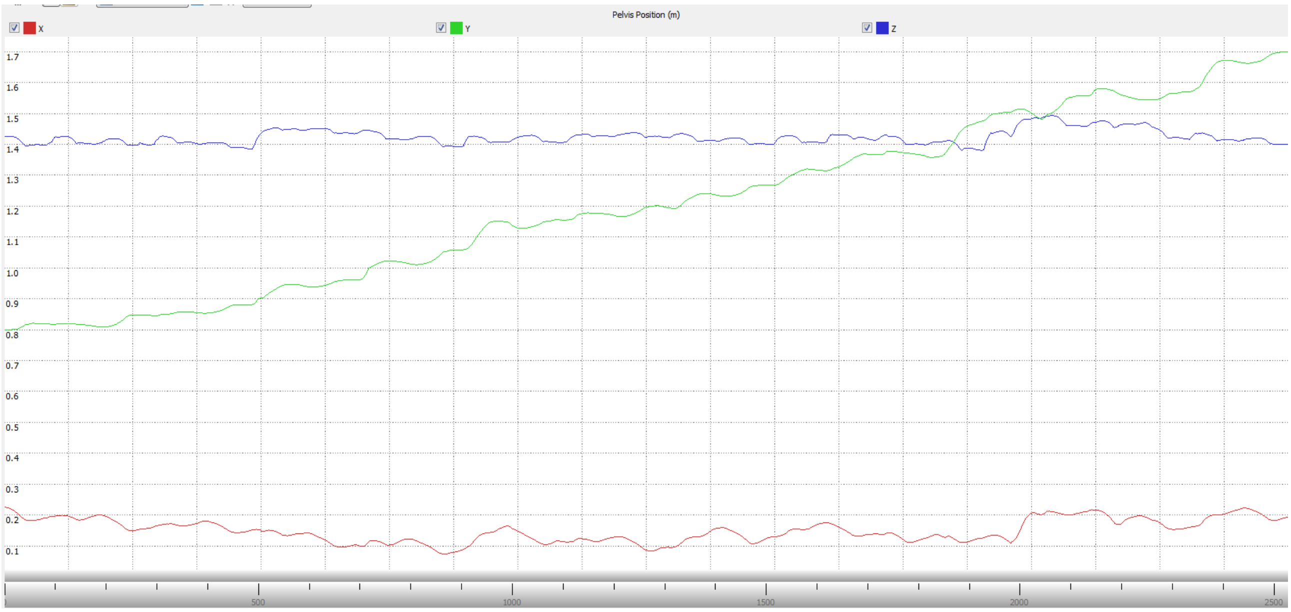


Figure 77. Fast trot position data for a non-professional rider

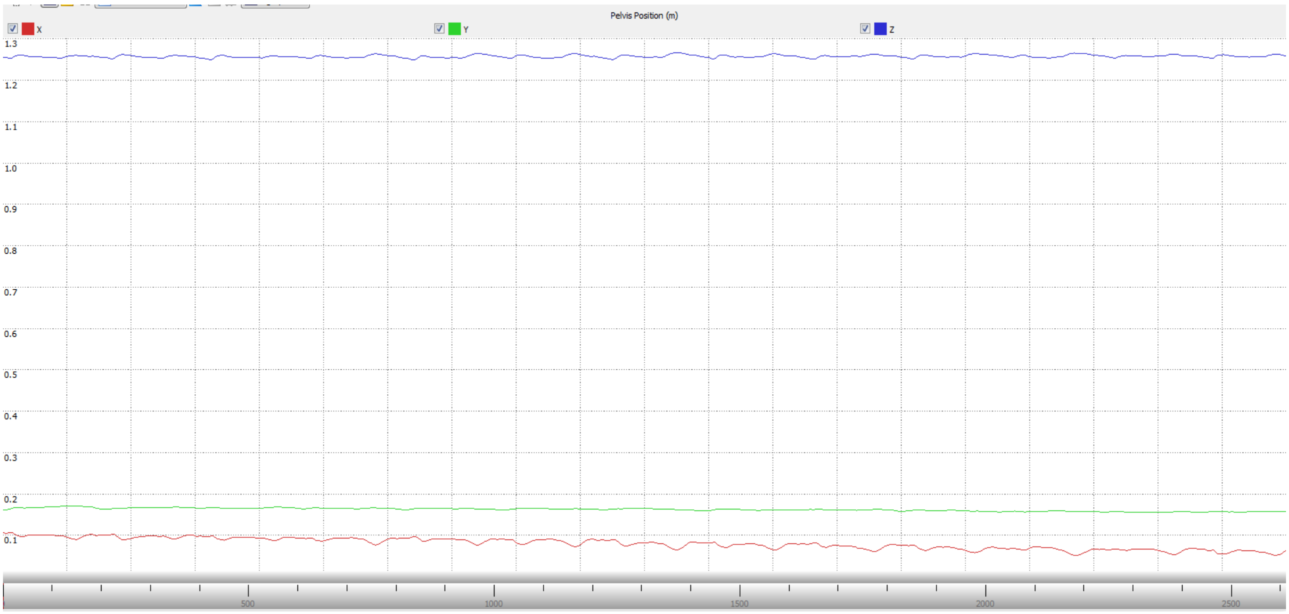


Figure 78. Fast trot position data for a professional rider

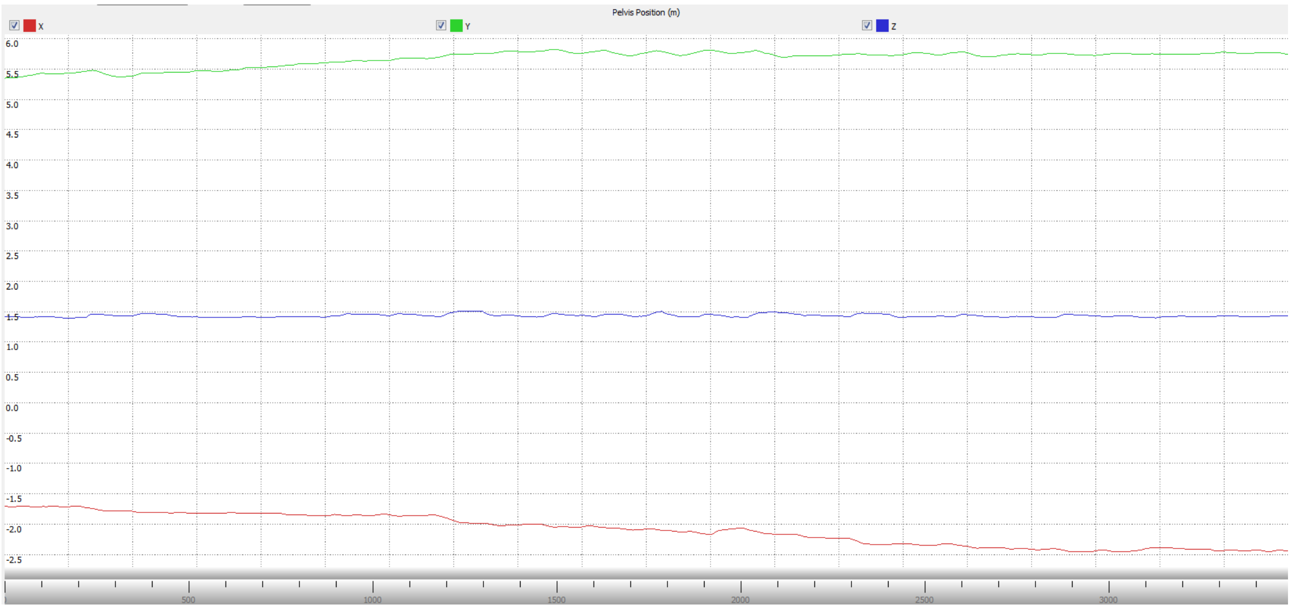


Figure 79. Slow gallop position data for a non-professional rider

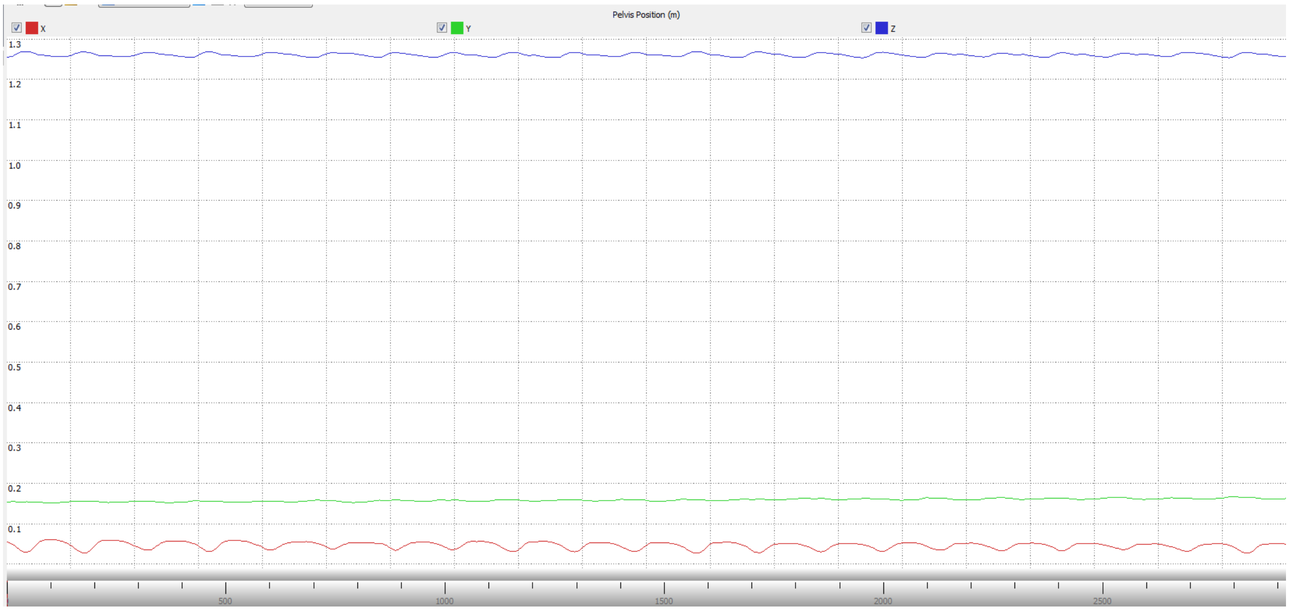


Figure 80. Slow gallop position data for a professional rider

Figure 81. Fast gallop position data for a non-professional rider

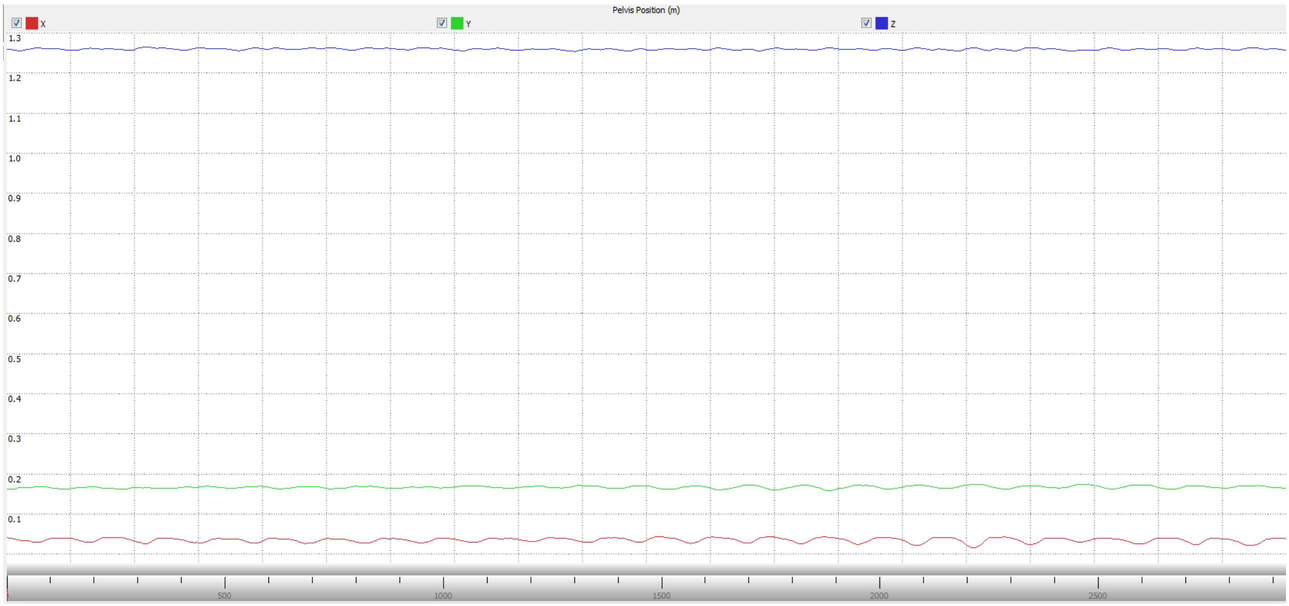


Figure 82. Fast gallop position data for professional rider

Measuring the position of the rider's pelvis it is important to understand how the pelvis behaves during riding. Pelvis of the rider should be fixed and resonate with horseback simulator's movements. By the results of pelvis position, the difference between professional and non-professional riders can be distinguished. The figures represent the position data for non-professional and professional riders, respectively. During all gaits, the results of the professional rider are steady without any significant changes along x, y and z-axes and oscillation. At slow walk gait for non-professional rider changes only along z-axes are small and more or less stable, but curves along x-axis decrease, y-axis increase. At fast walk gait, there is displacement along all three axes, the curve along the x-axis decreases, and the amplitude of the x-axis is major for the non-professional rider. The amplitude of the professional rider slightly increased. During slot trot of the non-professional rider there are almost no changes along z-axis although oscillation is high, and curves along the x-axis decrease, y-axis increase. At fast trot of the non-professional rider, the x and z-axes are more or less stable, the curve along the y-axis increases, although amplitude and oscillation are moderate. There are significant changes in the values at y-axis and between the figures for professional and non-professional riders at a slow and fast gallop. For non-professional rider at slow and fast gallop gait curves along x-axis decrease, y-axis increase, and the z-axis is stable.

Orientation data for the gaits such as slow and fast walk, trot, and gallop for the non-professional and professional rider, respectively, are shown on figures 83-94 below, where the x-axis is red, the y-axis is green, the z-axis is blue.

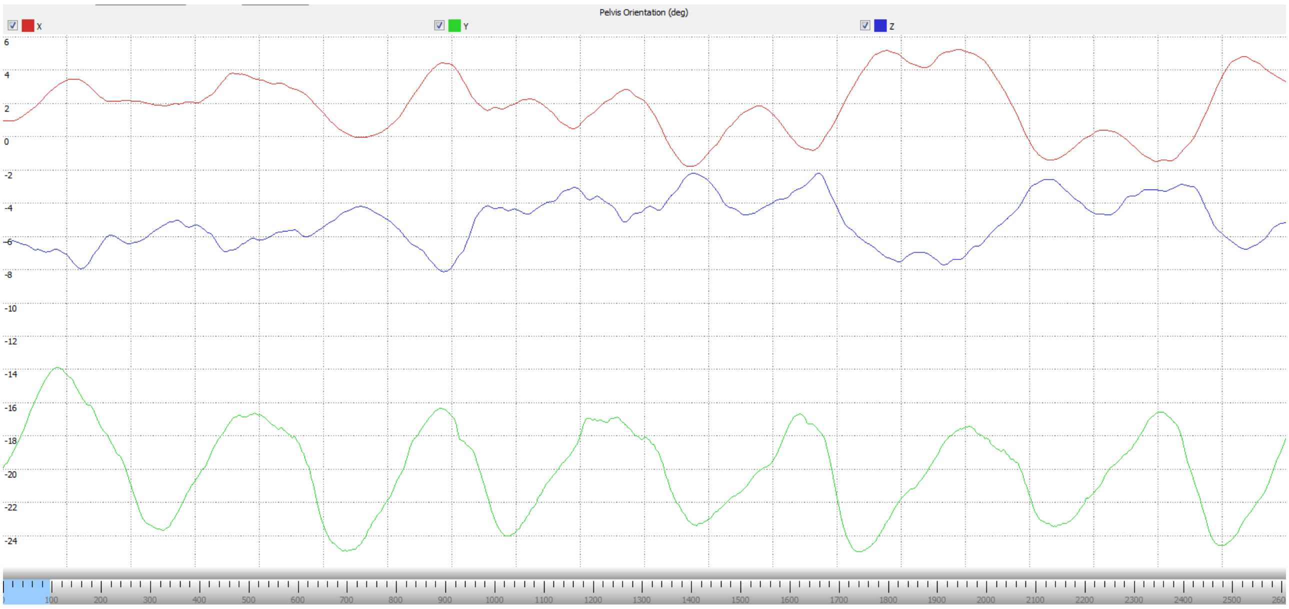


Figure 83. Slow walk orientation data for a non-professional rider

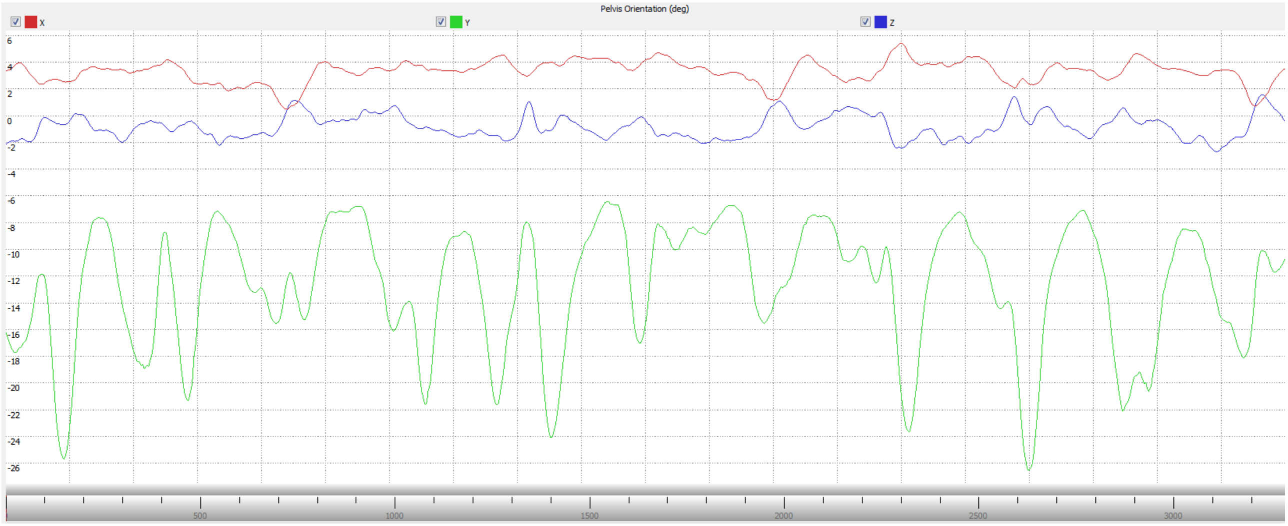


Figure 84. Slow walk orientation data for a professional rider

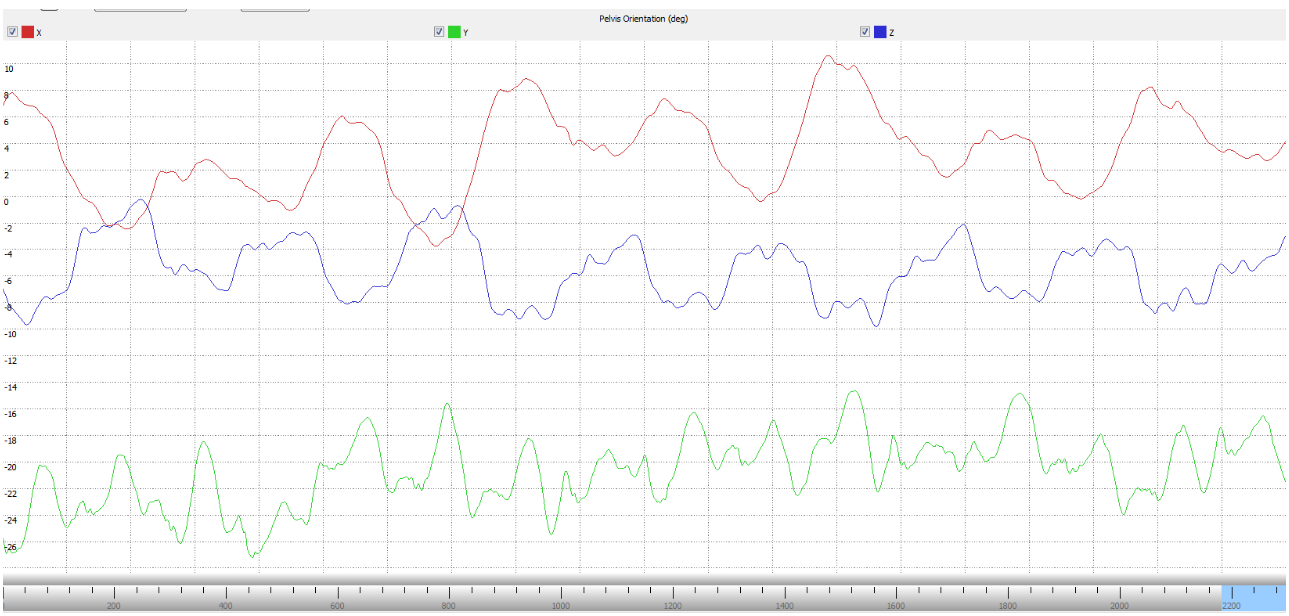


Figure 85. Fast walk orientation data for a non-professional rider

Figure 86. Fast walk orientation data for a professional rider

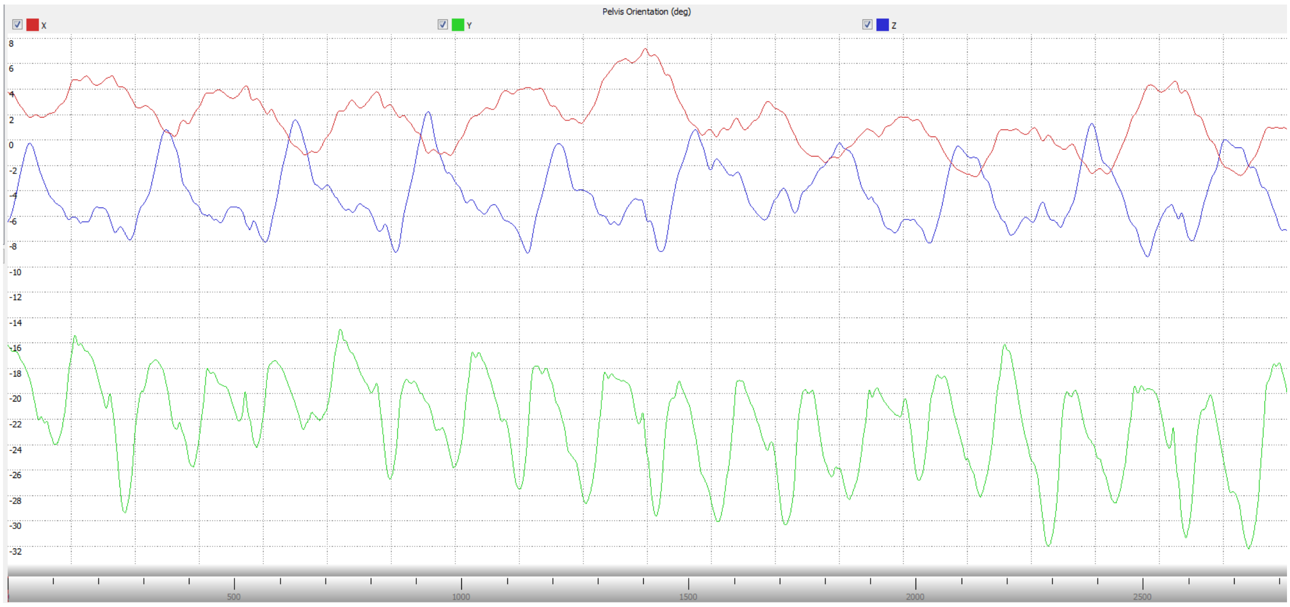


Figure 87. Slow trot orientation data for a non-professional rider

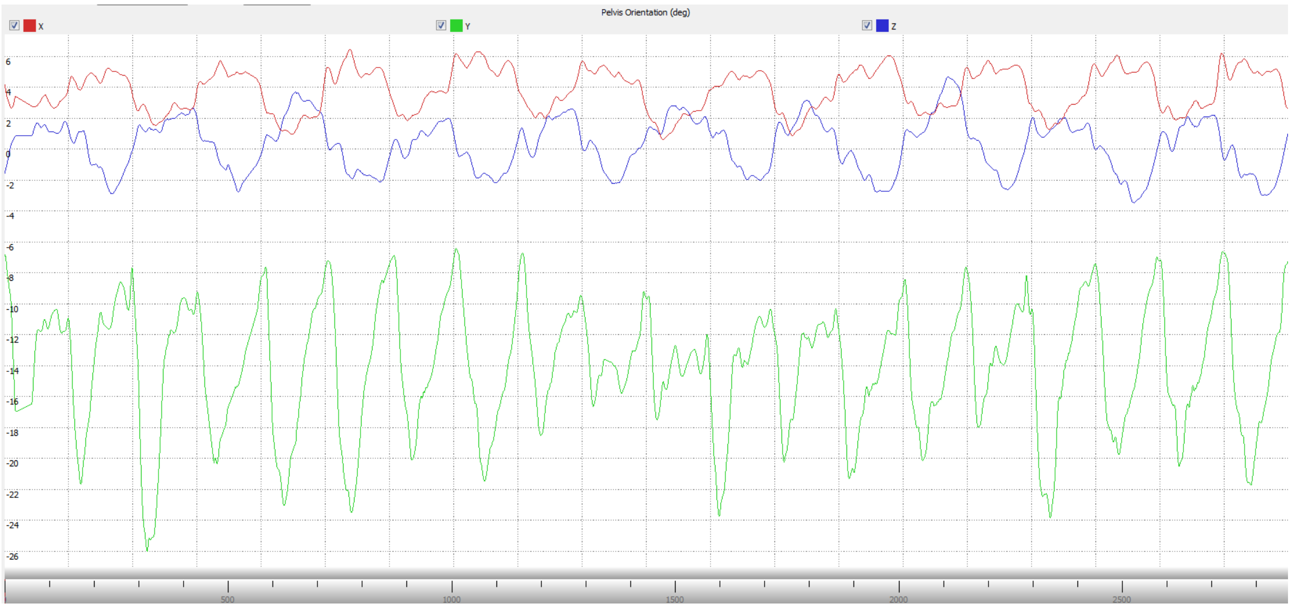


Figure 88. Slow trot orientation data for a professional rider

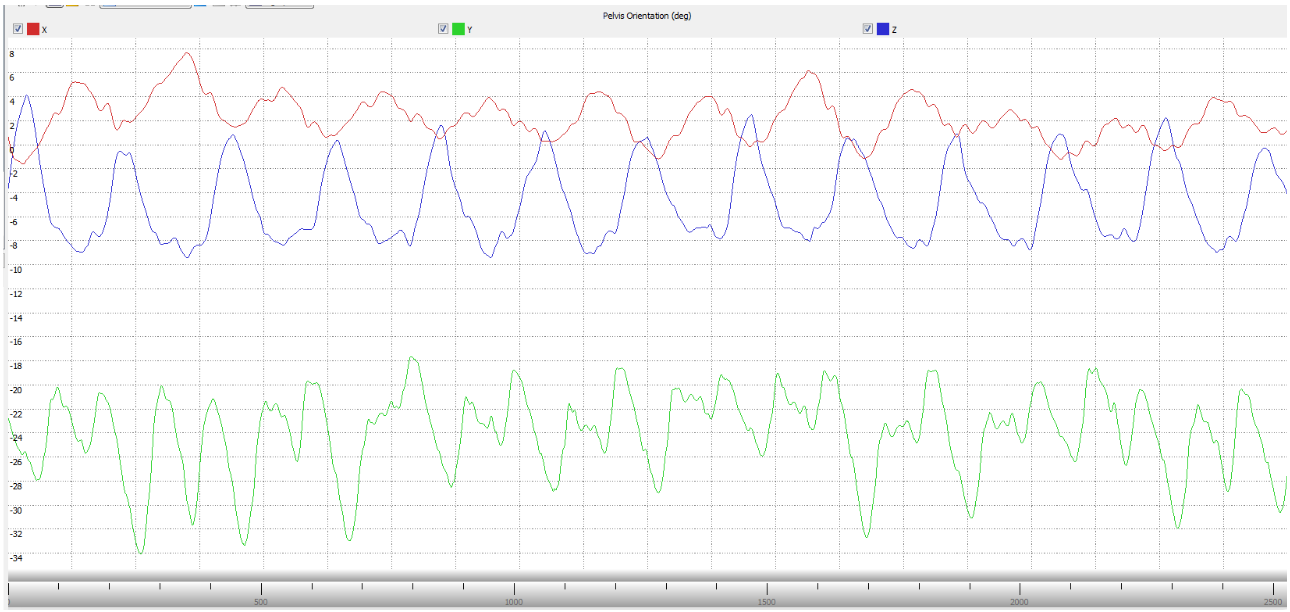


Figure 89. Fast trot orientation data for a non-professional rider

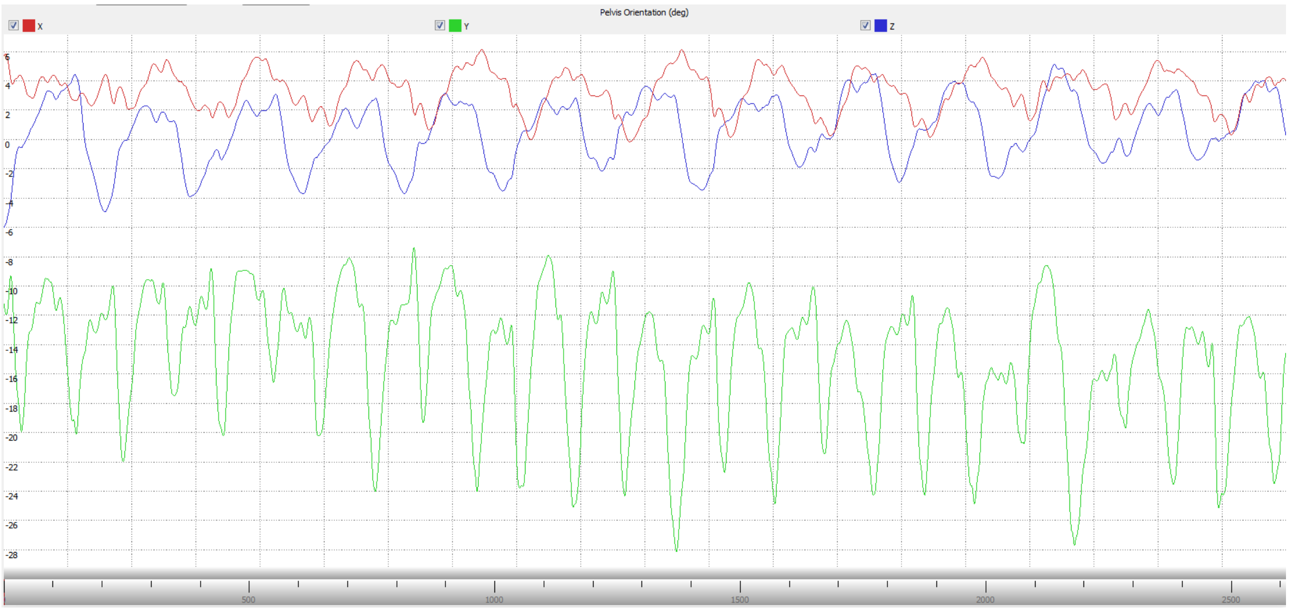


Figure 90. Fast trot orientation data for professional rider

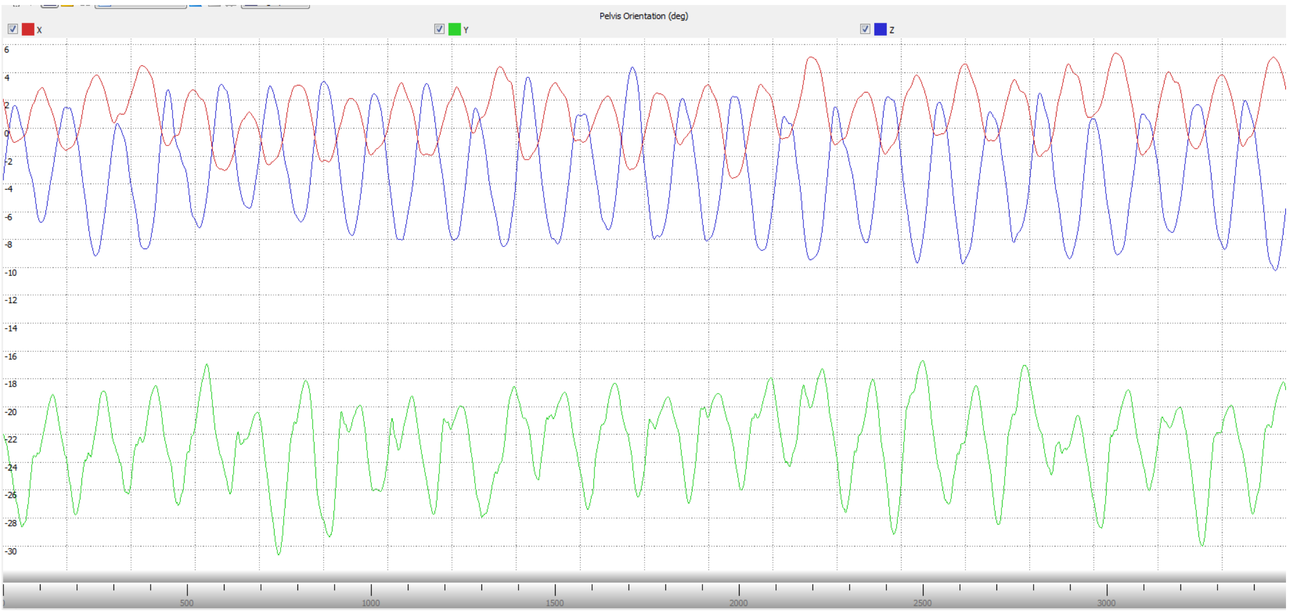


Figure 91. Slow gallop orientation data for a non-professional rider

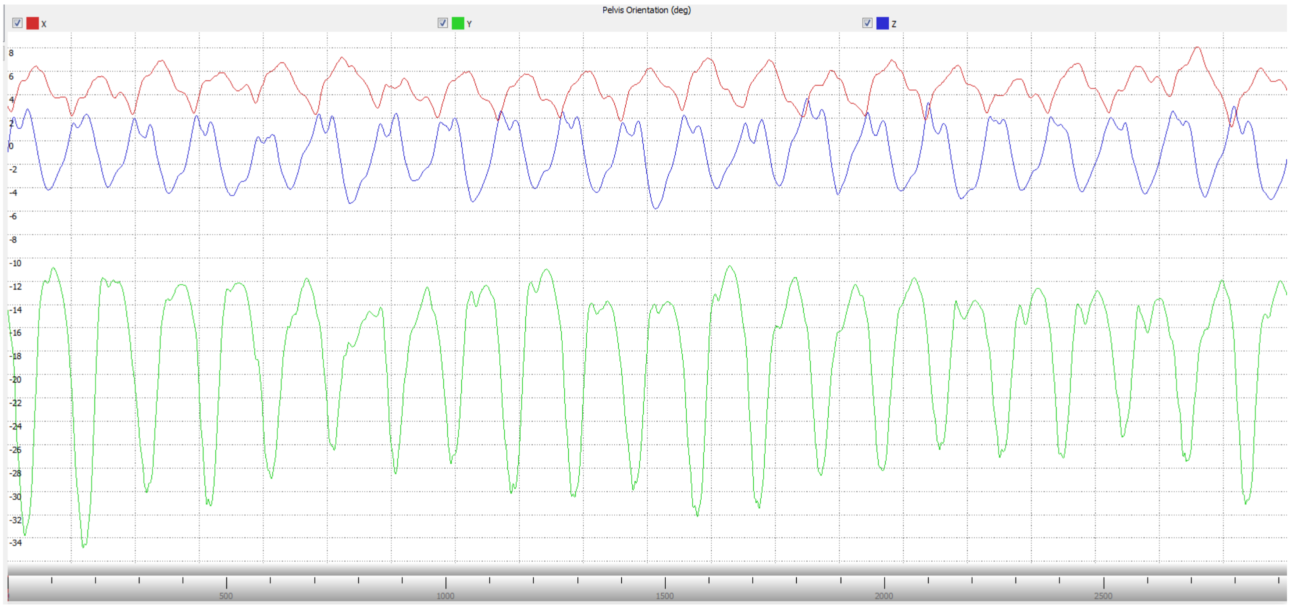


Figure 92. Slow gallop orientation data for professional rider

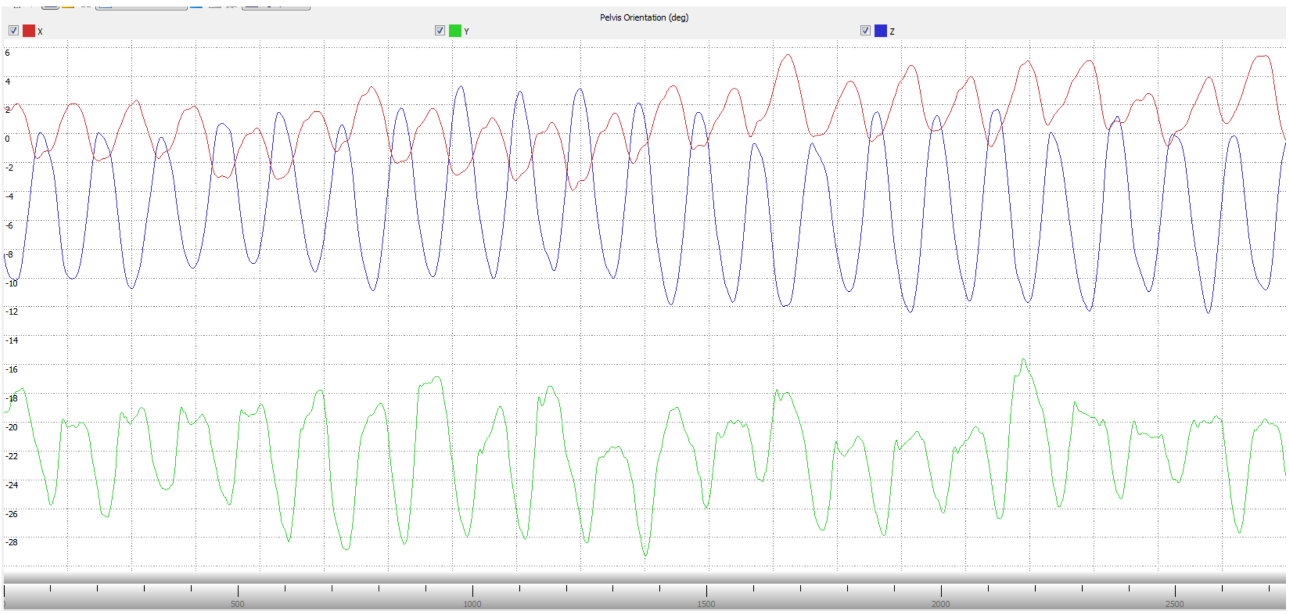


Figure 93. Fast gallop orientation data for a non-professional rider

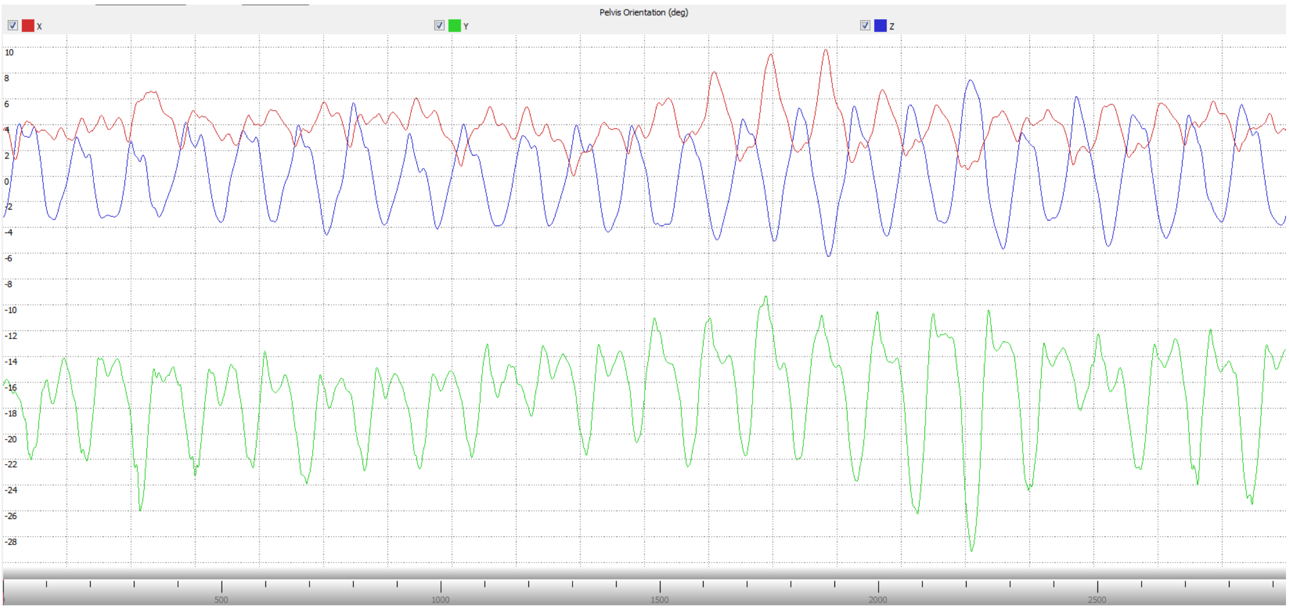


Figure 94. Fast gallop orientation data for professional rider

The figures illustrate orientation data for non-professional and professional riders for a slow and fast walk, trot and gallop, respectively. The results of the professional rider among all gaits show good quality and understanding of the process. At slow walk gait, the results from non-professional rider do not represent anything sensible, curves behaviour is chaotic. With respect to the professional rider, changes along the y-axis represent correct movements, skill and experience of horseback riding, moreover, increasing of y-axis shows good result. At the fast walk, the amplitude of x- and z-axes increases for the non-professional rider, and changes along y-axis look more than experiencing horseback riding compared to slow walk gait. The amplitude rises for the professional rider that can be explained as increasing of the speed. During slow and fast trot gaits there is no significant difference along x- and z-axes. The amplitude of the y-axis of the non-professional rider increases, but the amplitude of the professional rider is much higher. At slow gallop gait, the main drawback among all results of the non-professional rider is that x-axis is very smooth. The amplitude of the z-axis is extremely high, and the amplitude of the y-axis is slightly less compared to the professional rider. The results at fast gallop gait are mostly similar to slow gallop except that the amplitude of y-axis is lower, the z-axis is higher for the professional rider compared to slow gallop gait. For the non-professional rider the amplitude of z-axis increases, but the y-axis is stable.

Fixed pelvis and well-adjusted saddle allow the rider to avoid injuries and feel more conveniently, productively, and accurately. The rider should keep the pelvis in a neutral position without any rotation to avoid lumbar lordosis or anteriorly rotated pelvis. It is very essential to the rider to pay attention to the kinematic, especially, the position of the pelvis during riding and horse. Scientifically proven, that professional riders keep their pelvis closer to the centre of the saddle and further forward then non-professional riders, which tilt pelvis to the left or right and more backward. The wrong position in the saddle leads to the asymmetry in hip external rotation and back. With every horse's step rider receives force from the taken action. The force usually assumed by the lower part of the body such as the pelvis and hip joints. If rider's pelvis has wrong saddle position, then all force from movements will be absorbed by the lumbo-pelvic region. Incorrect capture of the force can lead to injuries in the upper region of the body, for instance, back asymmetry.

3.2 Motion Capture Based on Optical Experiment

The experiment took place in the simulation laboratory of Lappeenranta University of Technology where horseback riding simulator is located. Two people participated in the experiment. The first person is a female non-professional rider at the age of 18, height 165 cm and weight 47 kg never experienced riding procedure before, shown on figure 95.

Figure 95. Non-professional rider during the experiment

The second person is a female professional rider at the age of 24, height 163 cm and weight 60 kg with 15 years of horseback riding experience. Professional rider, shown on figure 96, equipped with correct marker placement on the body. 19 mm markers with rubber base were placed to the clothes of riders with second side tape. The camera system, including twelve Flex 3 V100R2 cameras, was placed in the self-made metal frame and calibrated

Figure 96. Professional rider with markers placement, front and back view

The aim of the experiment was to compare the body behaviour of the professional and non-professional riders while riding a horseback simulator with attention to the pelvis of riders using optical infrared marker-based motion capture system. In general, six modes were selected for data collection, such as a slow walk at speed 1, fast walk at speed 5, slow trot at speed 10, fast trot at speed 20, slow gallop at speed 25, and fast gallop at speed 35. The whole representation of the experiment in numbers can be found in table 5. Data were collected for 20 seconds with a time step of 0.01 second for each mode.

Table 5. Motion capture based on an optical method

Mode	Speed	Duration	Frequency	Time step
Slow walk	1	20 seconds	100 Hz	0.01 seconds
Fast walk	5	20 seconds	100 Hz	0.01 seconds
Slow trot	10	20 seconds	100 Hz	0.01 seconds
Fast trot	20	20 seconds	100 Hz	0.01 seconds
Slow gallop	25	20 seconds	100 Hz	0.01 seconds
Fast gallop	35	20 seconds	100 Hz	0.01 seconds

Data were recorded using the NaturalPoint Tracking Tools software. An example of recorded data is shown on figure 97.

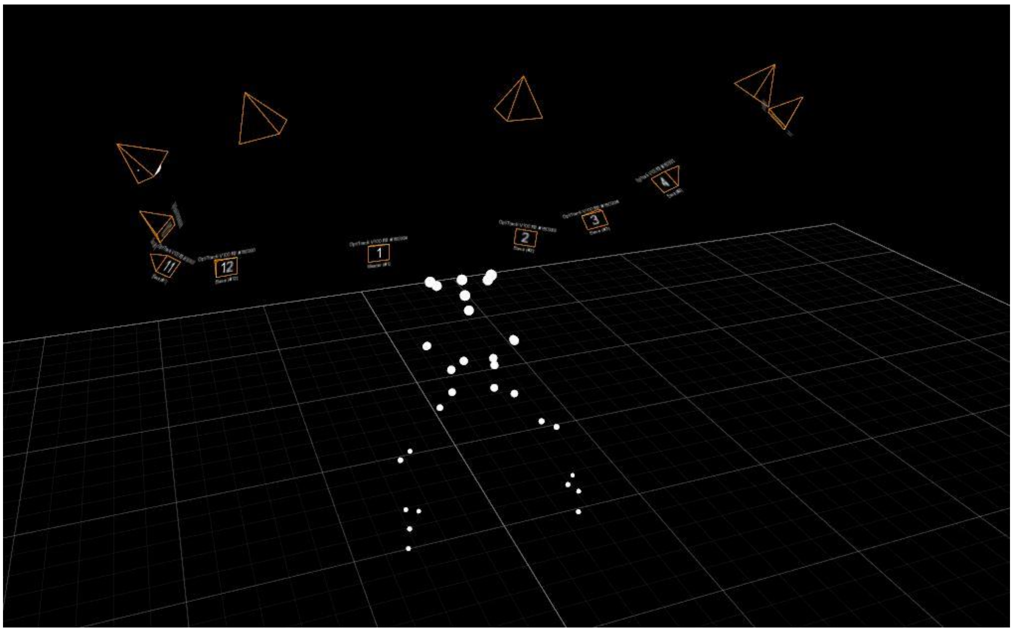


Figure 97. Recorded data from the NaturalPoint Tracking Tools software

The software allows to create rigid bodies which consist of at least three markers placed around joints and measure the position (in millimetres) by three axes x, y, z and the orientation (in degrees) by three axes yaw, pitch, and roll as a real-time information.

Recorded data only allows to view real-time information for position and orientation without graphs or arrays of values, however, while exporting timeline data in CSV file it is only possible to view the position of a trackable. Timeline data was exported in CSV format, then exported to Microsoft Excel, and sorted by trackable name to observe and normalized into the equal time strides for each mode. For the professional rider, time strides account 1200 points and for non-professional rider, time strides account 1700 points. Microsoft Excel does not allow to build graphs more than a column width of 255 signs and row height of 409 signs. Also, the data should be filtered, for that purpose self-written Matlab script with the low-pass filter was used. The example of not filtered and filtered position data for slow walk gait of the horseback simulator for the non-professional and professional rider is shown on figures 98, 99 and figures 100, 101, respectively, where the x-axis is blue, the y-axis is red, the z-axis is yellow.

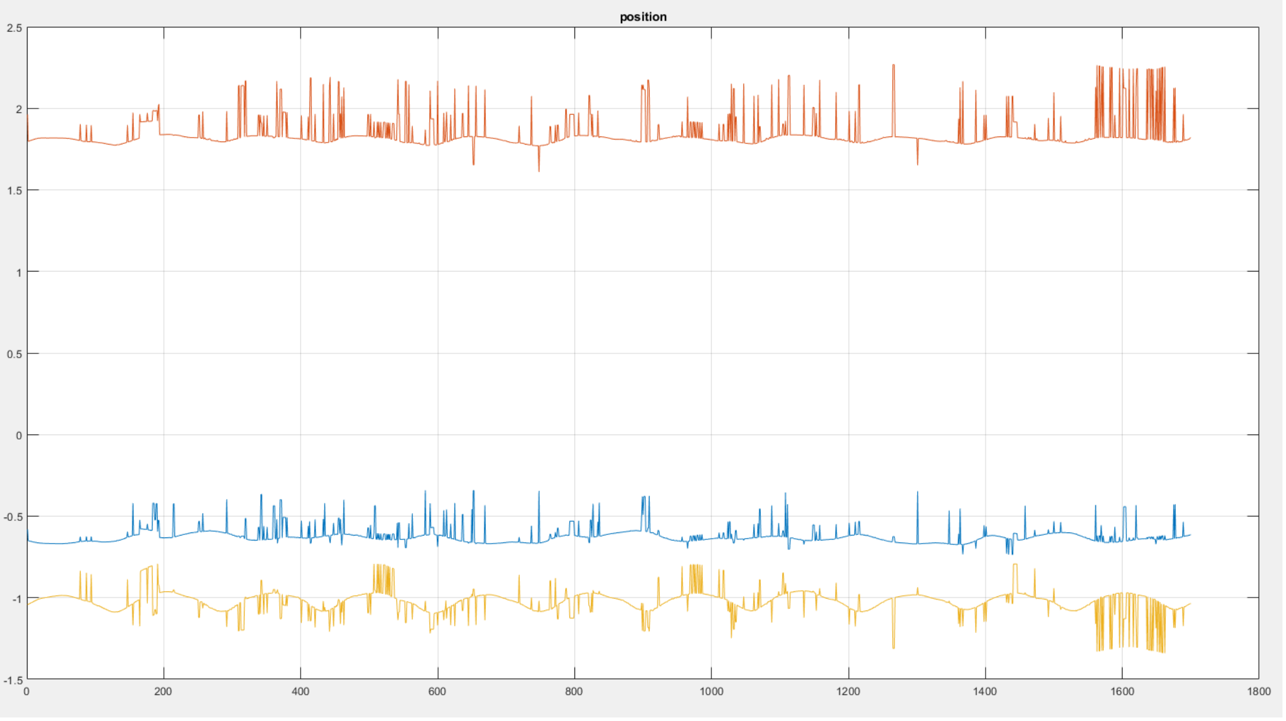


Figure 98. Slow walk not filtered data for a non-professional rider

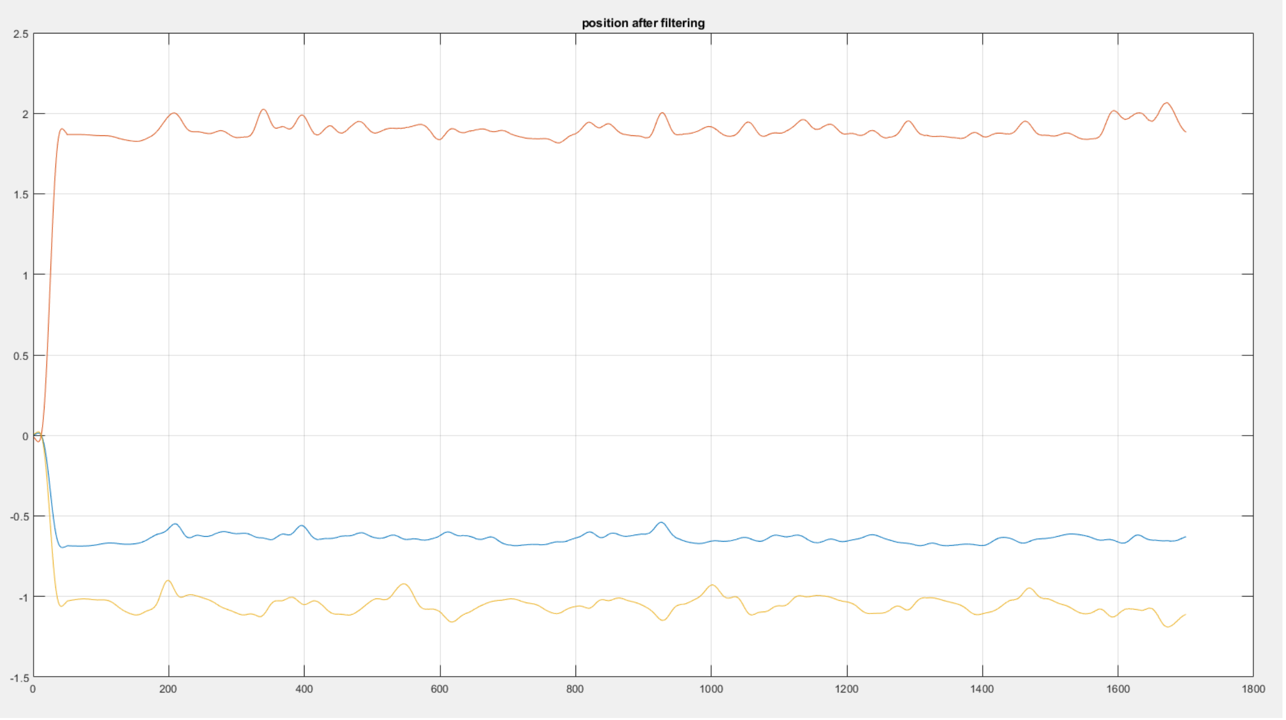


Figure 99. Slow walk filtered data for a non-professional rider

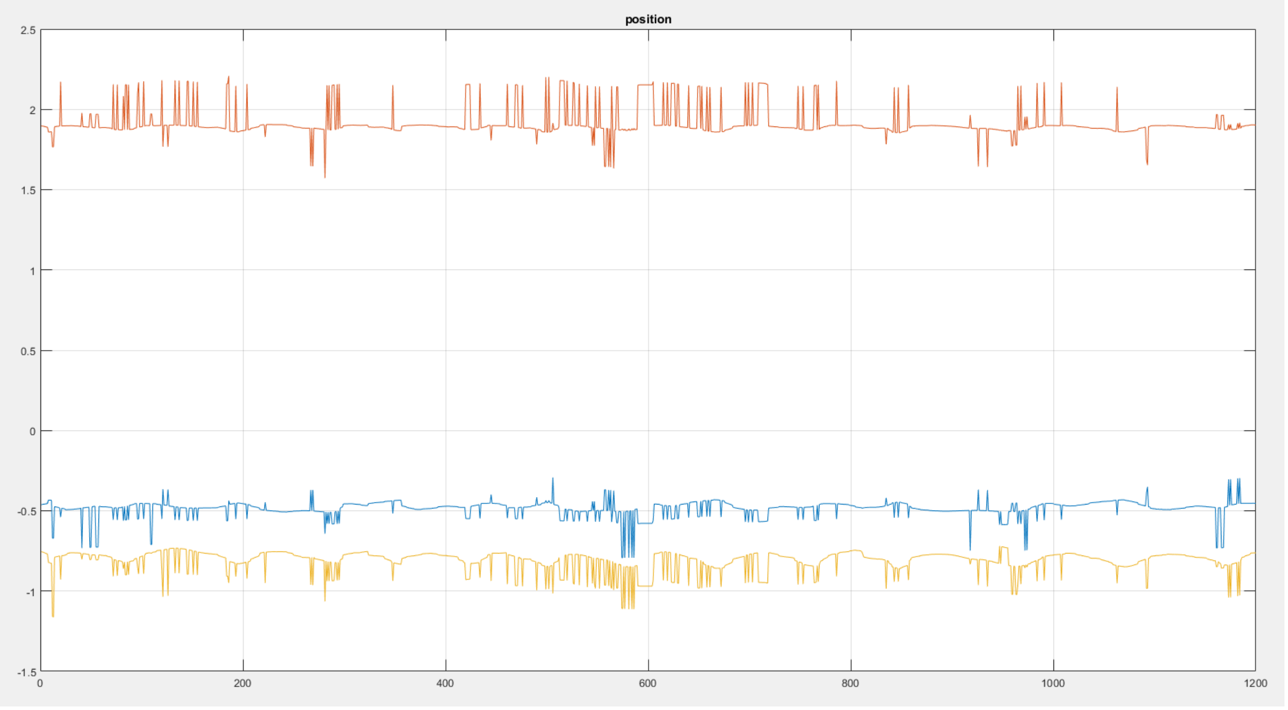


Figure 100. Slow walk not filtered data for a professional rider

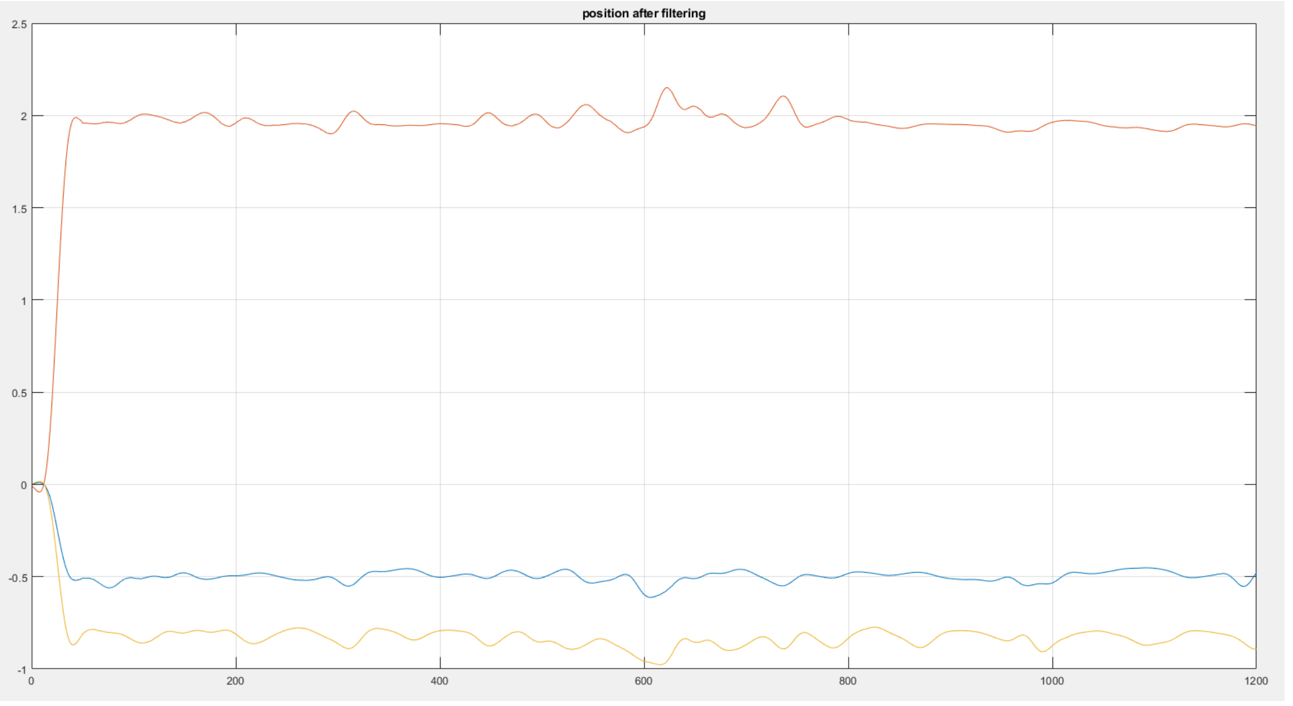


Figure 101. Slow walk filtered data for a professional rider

Filtered position data for the rest of gaits such as fast walk, slow and fast trot, slow and fast gallop for the non-professional and professional rider, respectively, is shown on figures 102-111 below.

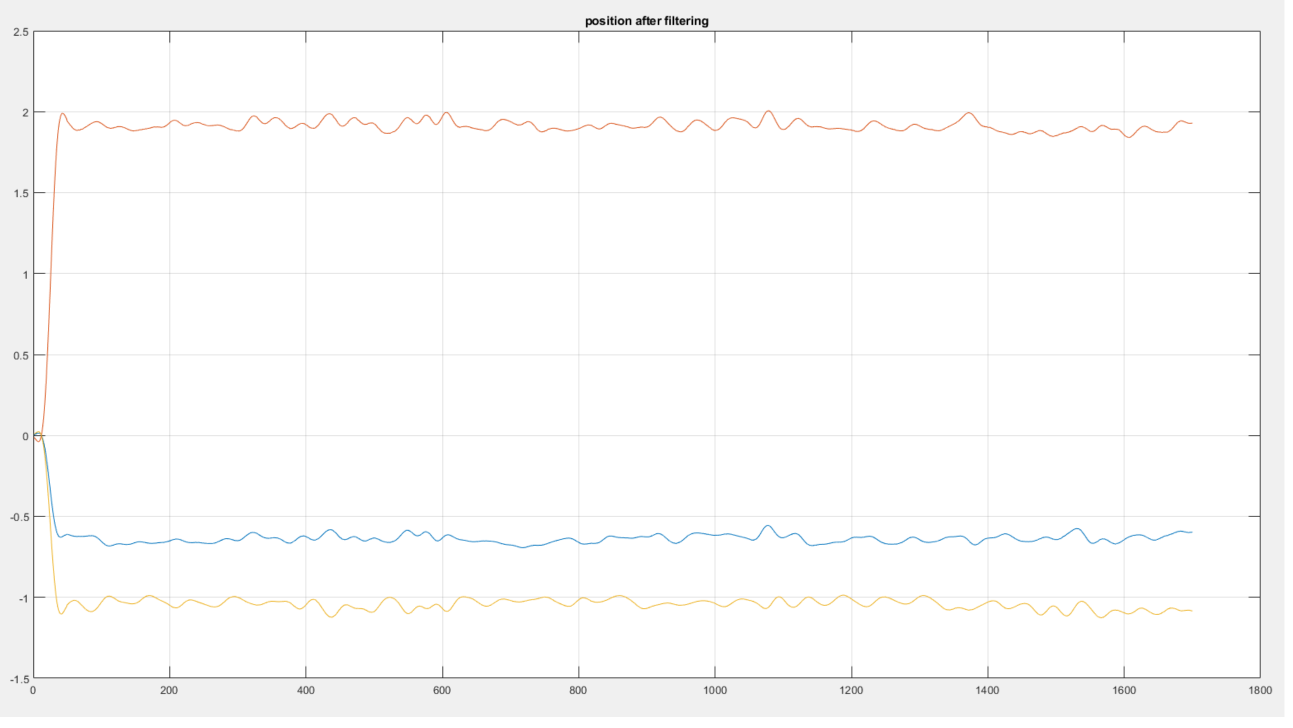


Figure 102. Fast walk filtered data for a non-professional rider

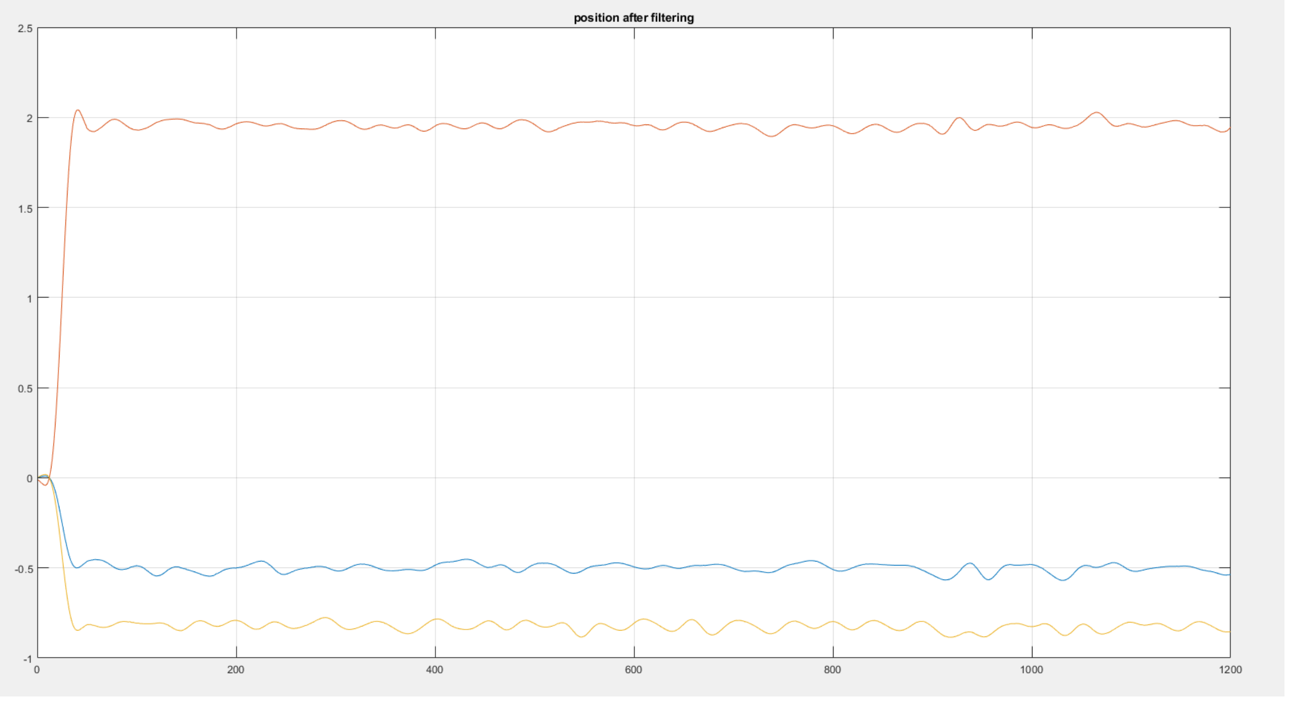


Figure 103. Fast walk filtered data for a professional rider

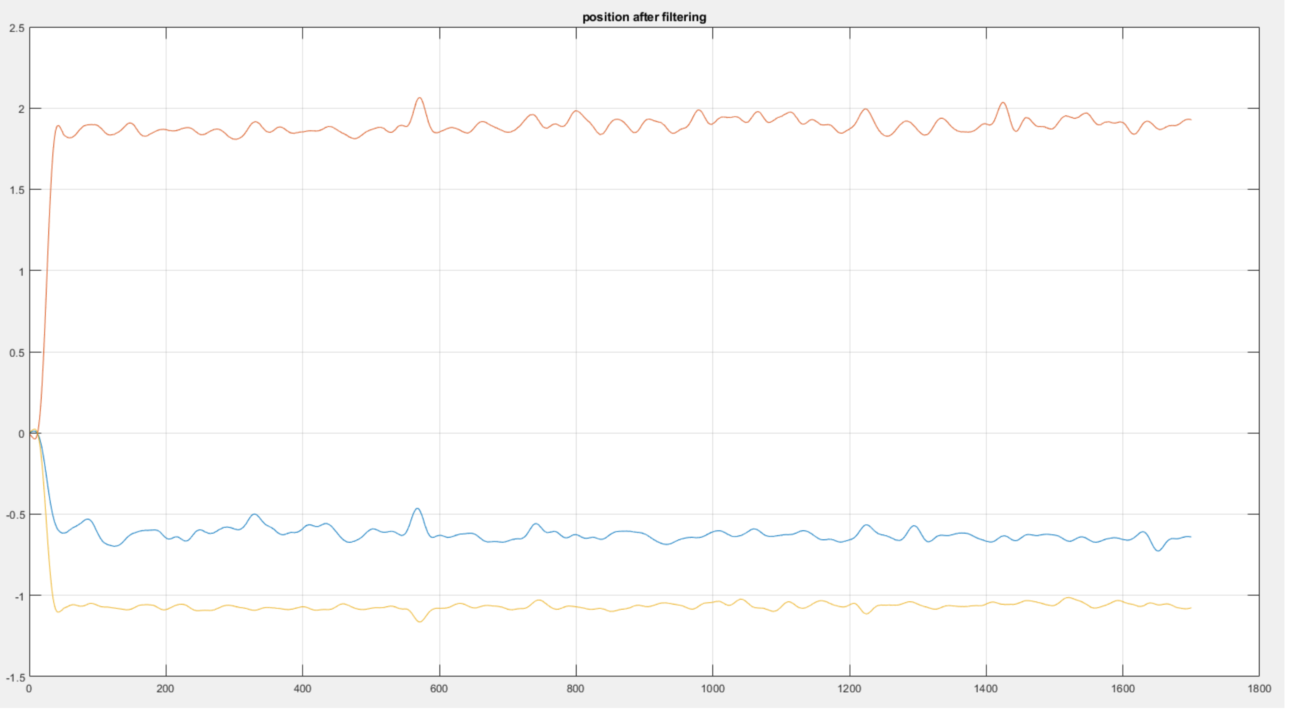


Figure 104. Slow trot filtered data for a non-professional rider

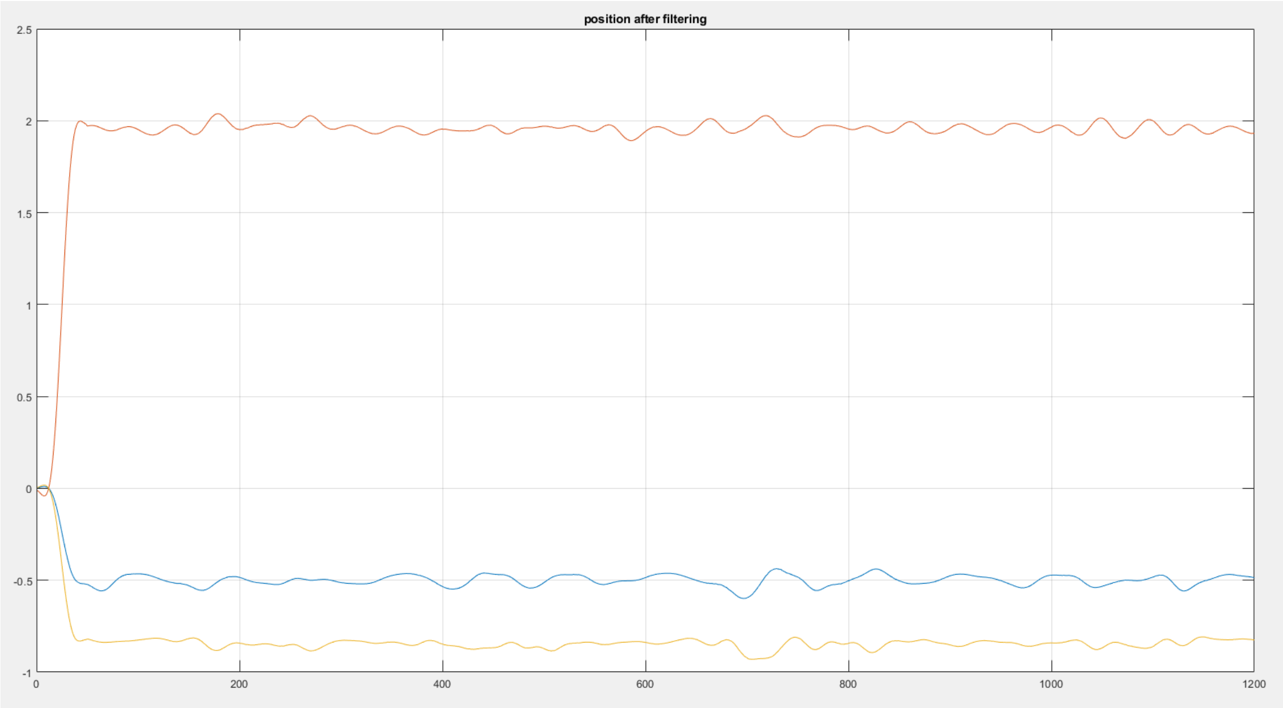


Figure 105. Slow trot filtered data for a professional rider

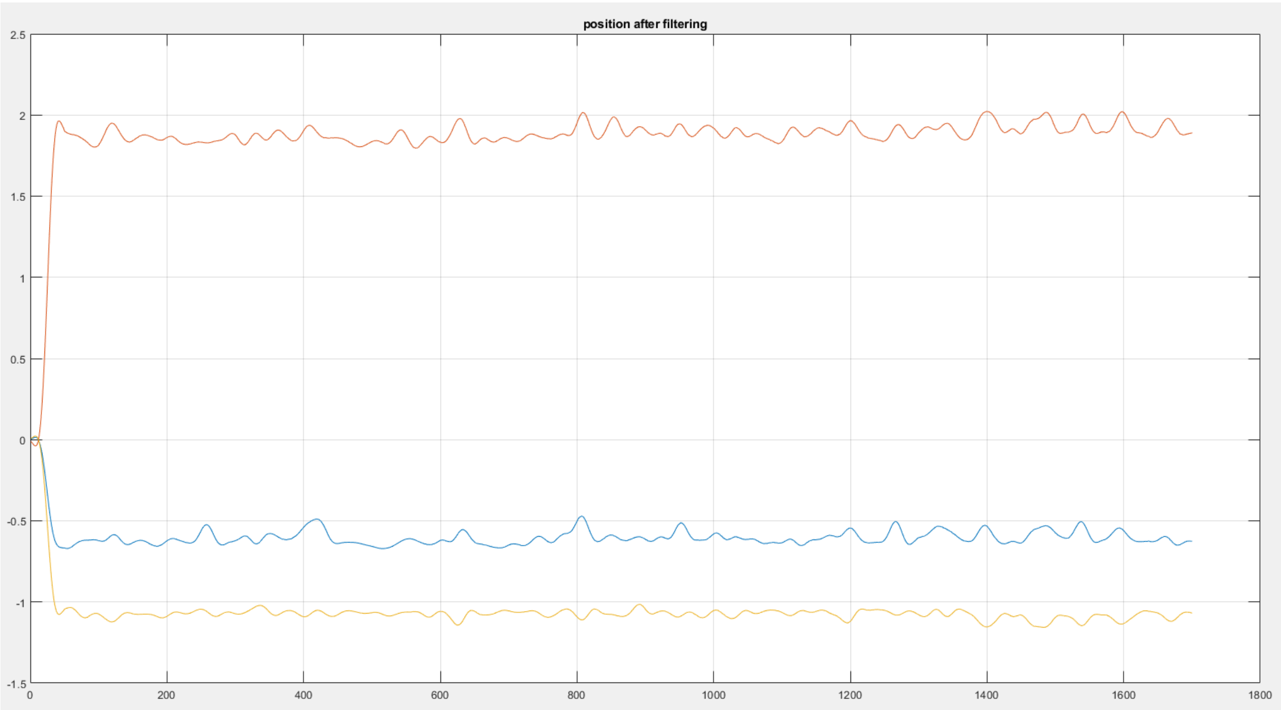


Figure 106. Fast trot filtered data for a non-professional rider

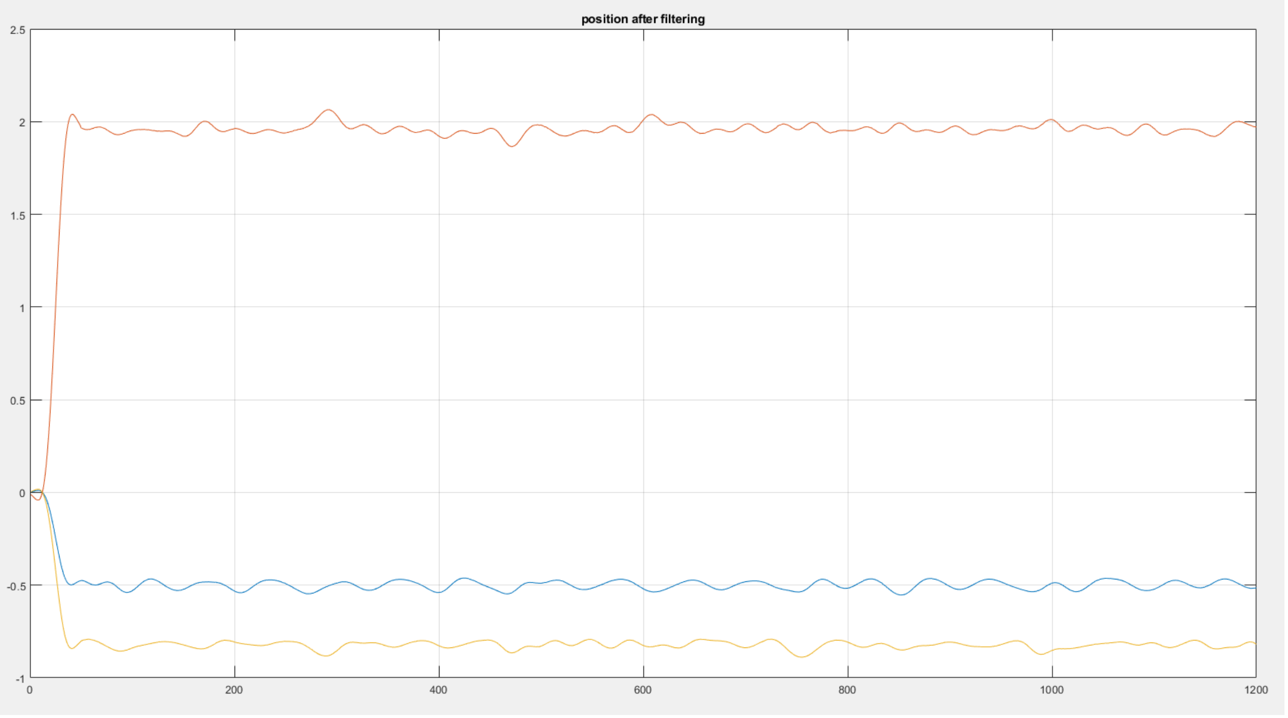


Figure 107. Fast trot filtered data for professional rider

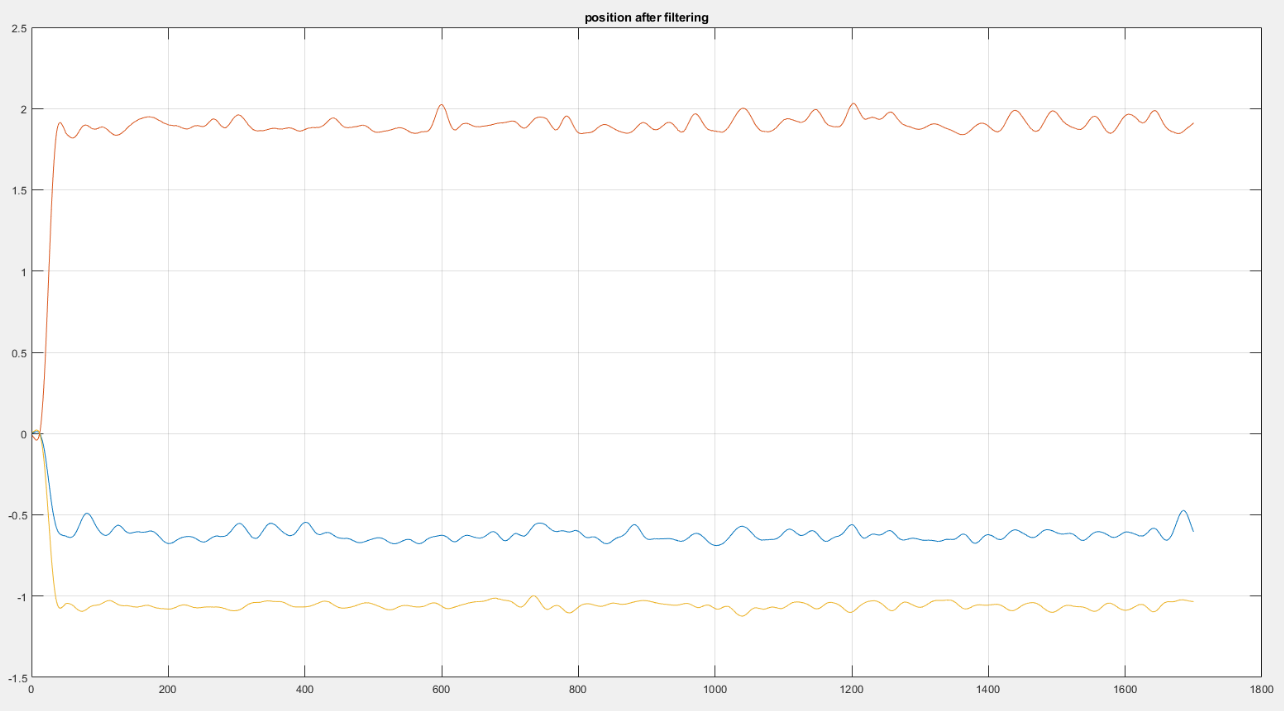


Figure 108. Slow gallop filtered data for a non-professional rider

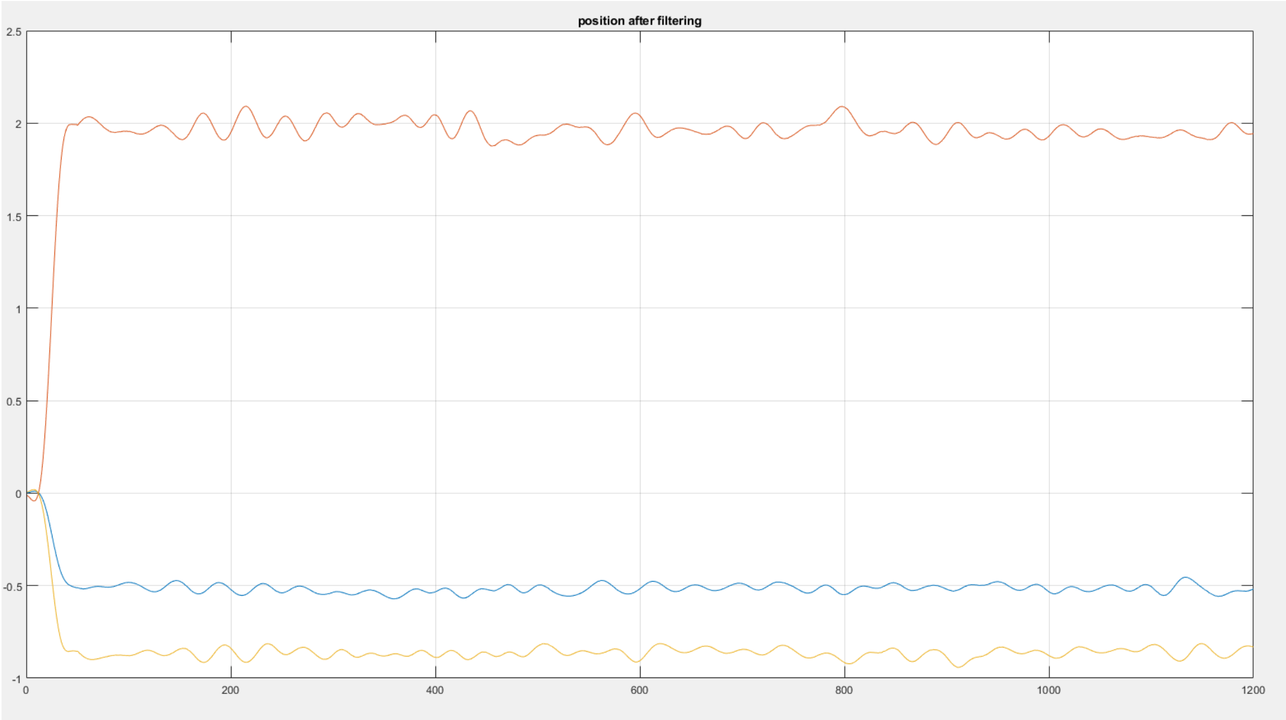


Figure 109. Slow gallop filtered data for professional rider

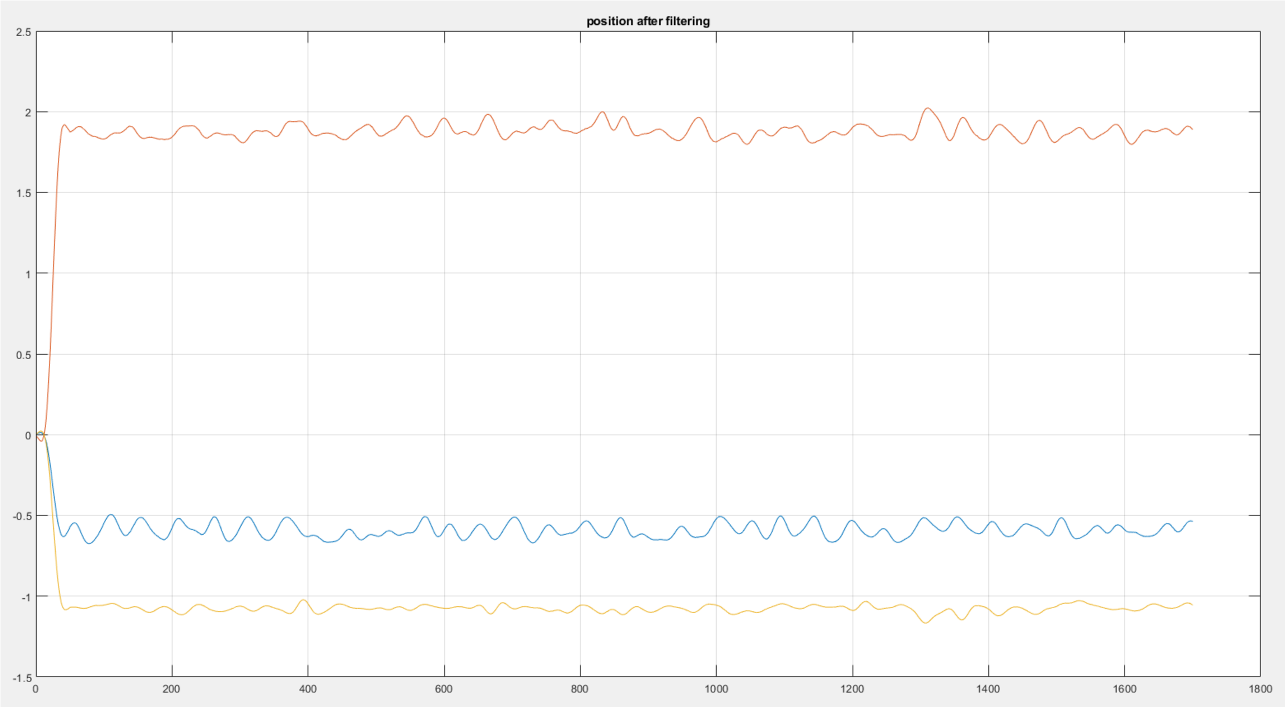


Figure 110. Fast gallop filtered data for a non-professional rider

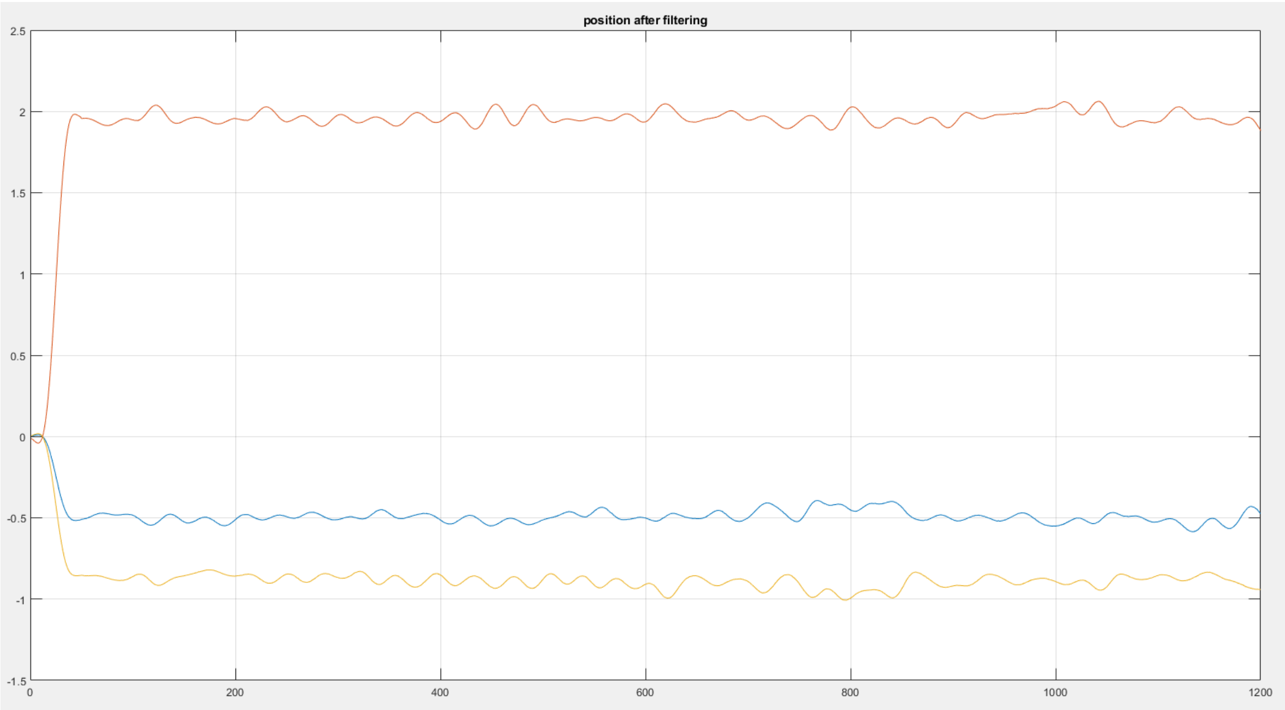


Figure 111. Fast gallop filtered data for professional rider

The load from riding depends on the gait of the horse. For instance, the horse's gait trot is equal to an active walking of a human, gallop is equal to a run. During quiet riding, a person experiences much less impact on the joints and spine than with fast walking or running. It is seen from all graphs that the position of the pelvis of the professional rider changes on a smoother trajectory with lower amplitude compared to the non-professional rider. This is due to the fact that the professional rider has more experience in riding, knows how to find a correct position in the saddle and is able to maintain upright trunk position. Also, professional rider knows how to control the body and how to interact with the horse while riding. Especially, lower amplitude of the professional rider compared to the non-professional can be observed during the slow trot. On the slow and fast walk modes, the movements of the simulator are sharp what leads to the increase of amplitude. During walking both real horse's and simulator's movements are sharp because of the physical structure of the horse and gait type. While walking the horse's hip lifts and pushes the rider's pelvis forward and backwards. Observing the results of the slow and fast gallop, which are very similar for professional and non-professional riders, leads to the conclusion that for the non-professional rider it is easier to balance on the horse during a gallop, whereas this gait is similar to the running condition of the human.

The rider who has never experienced horseback riding before may make mistakes of pelvis movements in the saddle that can lead to the asymmetry in hip external rotation and back. It is very essential to the rider to pay attention to the kinematic, especially, the position of the pelvis during riding and horse. All the movements that a rider receives from the horse are absorbed mostly by the lower region of the body such as the pelvis and hip joints. If the rider loss any mobility at the pelvic region, then all force from the horse's movements will transfer to the lumbo-pelvic region. Incorrect absorption of movements can cause injuries in the upper part of the body, especially back injuries as it is the most vulnerable area. The rider should keep the pelvis in a neutral position without any rotation to avoid lumbar lordosis or anteriorly rotated pelvis. Scientifically proven, that professional riders keep their pelvis closer to the centre of the saddle and further forward then non-professional riders, which tilt pelvis to the left or right and more backward.

3.3 Brain Monitoring Utilizing EEG

The experiment took place in the simulation laboratory of Lappeenranta University of Technology where horseback riding simulator is located. One person participated in the experiment. The person is a female professional rider at the age of 21, height 155 cm and weight 48 kg with 13 years of horseback riding experience, shown on figure 112.

Figure 112. Professional rider during EEG experiment

The aim of the experiment was to monitor the behaviour of a brain of the professional rider during a long time and riding horseback simulator for the first time. Using Neuroelectrics Instrument Controller (NIC) software a brain map was created with a standard amount of wires, shown on figure 113. Following brain map cover all parts of the brain needed in the experiment, for instance, vision, concentration, moving, and hearing.

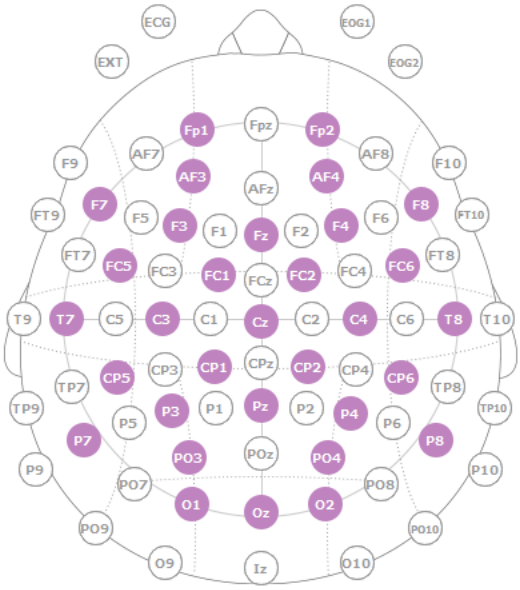


Figure 113. Brain map

In general, six modes were selected for data collection, such as a slow walk at speed 1, fast walk at speed 5, slow trot at speed 10, fast trot at speed 20, slow gallop at speed 25, and fast gallop at speed 35. The whole representation of the experiment in numbers can be found in table 6. Data were collected for 25 minutes and 45 seconds with a time step of 1 second during recording and approximately 1 minute for each mode.

Table 6. Measurement session for EEG experiment

Mode	Speed	Duration	Frequency	Time step
Start. Sitting on a chair	0	0-1:08	500 Hz	1 second
Moving up to horse	0	1:08-1:16	500 Hz	1 second
Sitting on the horse	0	1:16-2:15	500 Hz	1 second
Horse is on up position	0	2:15-4:30	500 Hz	1 second
Slow walk	1	4:40-5:40	500 Hz	1 second
Close eyes	1	5:40-6:12	500 Hz	1 second
Open eyes	1	6:12-6:20	500 Hz	1 second
Blink	1	6:20-6:25	500 Hz	1 second
Fast walk	5	6:25-7:02	500 Hz	1 second
Slow trot	10	7:02-9:02	500 Hz	1 second
Fast trot	20	9:02-11:03	500 Hz	1 second
Slow gallop	25	11:03-13:00	500 Hz	1 second
Fast gallop	35	13:00-15:00	500 Hz	1 second
Slow gallop	25	15:00-17:08	500 Hz	1 second
Fast trot	20	17:08-18:00	500 Hz	1 second
Slow trot	10	18:00-19:00	500 Hz	1 second
Fast walk	5	19:00-20:00	500 Hz	1 second
Slow walk	1	20:00-21:00	500 Hz	1 second
Horse is on down position	0	21:00-22:00	500 Hz	1 second
Sitting on the horse	0	22:00-23:11	500 Hz	1 second
Sitting on a chair	0	23:11-24:00	500 Hz	1 second
Standard questions. Finish	0	24:00-25:45	500 Hz	1 second

Data were recorded using the Neuroelectrics NIC software. An example of recorded data is shown on figure 114.

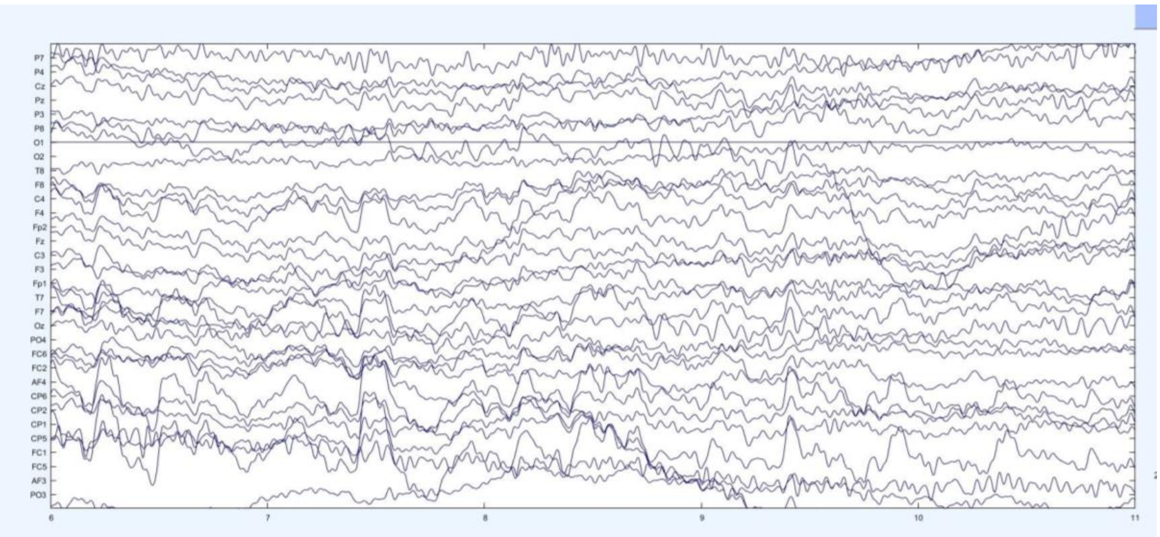


Figure 114. Recorded data from the Neuroelectrics NIC software

For data processing, Neuroelectrics NIC OFFLINE software was used. Using Neuroelectrics NIC OFFLINE software there is a possibility to manage and edit recordings, visualize EEG data using brain scalp maps, and visualize electric fields in cortical space. The software allows to use 15% of data by default for plotting, but in this case, 100% of data was used. Due to the fact that the simulation laboratory is full of different electronic devises data was recorded with noises. Filtering was made to get rid of the noise using self-written Matlab script with the help of Butterworth filter with frequency from 0.1 to 30 Hz. The EEG experiment results on scalp map are shown on figure 115 below.

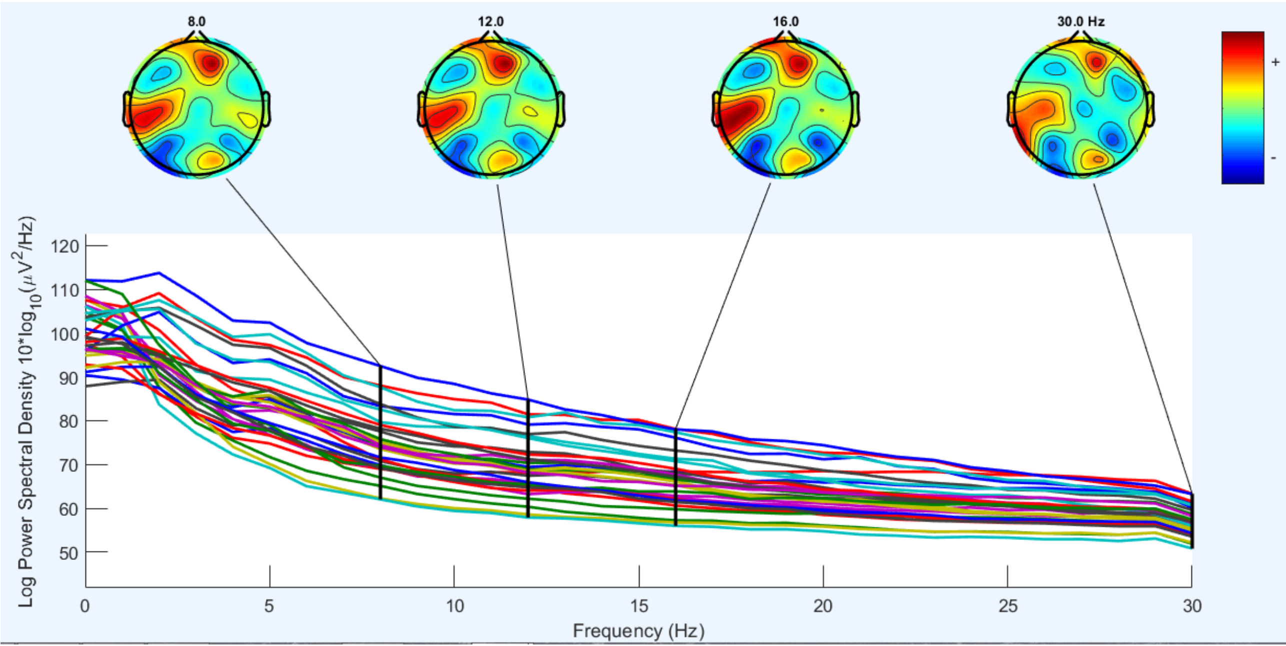


Figure 115. Scalp map

The cerebrum consists of two parts: the right and left hemispheres. Two parts connected with corpus callosum that works as a transmitter between two sides and helps to deliver messages from the left part to the right. The left hemisphere controls the right part of the body and the right hemisphere controls the left part of the body (Mayfield Clinic , 2016). The left hemisphere controls speech, comprehension, arithmetic, and writing and the right hemisphere controls creativity, spatial ability, artistic, and musical skills (Mayfield Clinic , 2016). Mostly, the left part of the brain controls hand usage and language, therefore 92% of people are right-handed. The cerebrum is divided into frontal, parietal, occipital and temporal parts. The frontal lobe is responsible for emotions, planning, speaking, body movements, intelligence and concentration. Parietal and occipital lobes indicate vision, sense of touch, pain and language, words interpretation. The temporal lobe is responsible for hearing, understanding and memory.

Basically, electroencephalography frequency is divided into low and high frequencies. Low frequency is in the range from 0.1 Hz to 8 Hz, high frequency is in the range from 8 Hz to 30 Hz. From the figure 114, it can be noted that a low frequency of 0.1 Hz corresponds to a dark blue colour and high frequency of 30 Hz corresponds to a deep red. Low frequency, usually, is responsible for relaxing and sleeping time, while high frequency from 8 Hz to 30 Hz is responsible for awaking time and different brain activities such as sport, mathematics, concentration and so on. In the field of our interest, there are only results expressing high frequency, nevertheless, if the graph with low-frequency results will be examined following trend will be noted.

At the beginning of the experiment, the professional rider was asked to sit for one minute on the chair and further on the horse without any movements, relaxed with closed eyes. On the scalp map, it is seen that the parts reflecting for vision in parietal and occipital lobes are highlighted with green/blue colour, but the temporal lobe responsible for hearing is highlighted in red. Occipital and temporal lobes in P4 domain are responsible for vision are always highlighted through all investigated frequencies. Parts of the brain responsible for hearing are highlighted in green/yellow. It means that there were no distracting noises or voices except the noise from the working horseback riding simulator. Observing the scalp map, higher activation accrues in the F4 domain in the frontal lobe (according to the brain map, shown on figure 112) that refers to intelligence, concentration, body movements, speaking, and emotions. Also, C3, CP5 domains are highlighted in red that relates to sensor-motor cortex and moving.

There is almost no difference between brain scalps on 8 and 12 Hz due to the fact that the professional rider knows horse gaits and how to control the body during different gaits of the horse. At 16 Hz frequency scalp map changes for greater concentration, activation in the F4 domain in the frontal lobe is even higher and coloured in dark red that can be caused by changing of horse gait and increasing the speed. At 30 Hz frequency the scalp map shows that occipital and temporal lobes in P4 responsible for vision are highlighted brighter, frontal lobe responsible for concentration is highlighted lighter, in consequence of the experiment completion to which the professional rider was warned in advance.

3.4 Integration and Comparison of Experimental Results

Motion capture – it is the method of animation of characters and objects. There are two major motion capture-based methods: optical and inertial. Optical-based motion capture method demands camera positioning around the frame of capturing. Markers covered with the special reflective material are main sensors to detect motion. Markers are usually placed to joints of the human body, which represent the most interest to the researcher. Markers reflect the infrared light coming from the cameras. The more cameras are used, the better since some body parts can be blocked by a shadow, an obstacle, and another part of the body during movements. 19 mm markers with rubber base were placed to the clothes of riders with second side tape. The camera system, including twelve Flex 3 V100R2 cameras, was placed in the self-made metal frame and calibrated. OptiTrack NaturalPoint TrackingTools software was used to record data. The software allows creating rigid bodies which consist of at least three markers placed around one joint. The software allows to obtain only position data in the offline mode and monitor orientation data in the real-time mode.

Inertial-based motion capture method uses inertial measurements units, which are built in sensors to detect position and movements. Usually, it includes gyroscopes, accelerometers and magnetometers. The Xsens MVN inertial motion capture system was used in the experiment. This system consists of the lycra suit, which is a special system for the motion capture of the human body. The Xsens MVN suit consists of 17 inertial MTx sensors, which are attached to key areas of the human body. The system estimates body segment orientation and position changes via gyroscope and accelerometer signals integration, real-time updating of twenty-three segment biomechanical model of the human body with twenty-two joints, automatically correcting for drift and errors. The motion tracker, attached to the suit on the lower back, is the miniature inertial measurement provides 3D angular velocity using rate gyroscopes, 3D acceleration using accelerometers, 3D earth magnetic field using magnetometers, as well as the barometer for measuring atmospheric pressure. The system was calibrated according to the manual in N-pose. The software allows obtaining acceleration, velocity, angular velocity, position and orientation data in the offline mode

Regarding the results obtained during two motion capture sessions, no significant difference between inertial and optical motion capture system was noticed with respect to the position. As it was explained earlier, NaturalPoint TrackingTools software allows obtaining only data position. The preliminary study suggests that optical based motion capture method has several drawbacks related to the size of whole equipment used in the experiment. The inertial motion capture Xsense suit takes up little space, calibration is fast, and also, the suit is easy to use, portable. There is no need to build special frames for camera system or has a special wanding tool for calibration. The MVN Studio software has a user-friendly interface. Using inertial motion capture system supplies better opportunity for data processing by providing more parameters to measure and monitor.

The optical motion capture method is not portable. Camera placement and camera calibration using wanding tool take a very long time to capture every piece of future captured volume, compared to inertial motion capture suit calibration, which takes approximately 7 minutes. Marker placement, also, is a time-consuming process, that requires basic knowledge of the human's body anatomy and additional equipment using for markers binding. The structure of markers is fragile, so markers are easy to break, what does not correspond the price for one single marker. There is a possibility to purchase a suit from OptiTrack and place markers on it with velcro adhesive material bottom, but the price of the suit is too high for a laboratory experiment. Furthermore, the software TrackingTools provided by NaturalPoint has not been updated in the simulation laboratory of Lappeenranta University of Technology for last 6 years, that makes harder to use the inundated software without manuals and customer support from the company. In the conclusion, between examined two different motion capture-based methods, the inertial motion capture system was recognized as a more convenient, comprehensive, complex, and easy to operate motion capture system.

3 CONCLUSION

Horseback riding as a form of therapy for a range of human disabilities has been spread worldwide recently. Benefits of horseback riding improve posture, balance, gross motor function, energy expenditure, and health state. Horseback riding has been found to be an effective form of therapy in other musculoskeletal disorders. In this work, real-time monitoring of human body during horseback riding utilizing a horse simulator was conducted. Three different experiments were made in order to monitor the behaviour of the body and brain for professional and non-professional horseback riders. The first and second experiments are based on inertial and optical motion capture system and represent body behaviour, respectively. The third experiment based on electroencephalography for monitoring brain behaviour.

Strong bioenergetic impulses are projected onto the human body from the powerful muscles of the horse. Also, during the session, the patient's muscles warm up and become plastic – the body temperature of the horse is one and a half degrees higher than inhuman. When moving, the horse transmits to the patient from 90 to 110 multidirectional motor impulses per minute: up-down along the length of the body axis (aa gainst gravity), forward-backward along the frontal-transverse axis of the body, from side to side around the sagittal-transverse axis of the body, diagonal movements around the functional point of the body centre. The movements of the horse are transferred to the middle position of the seated person, his hip joint and lumbar-vertebral column, imitating and stimulating the movements that a healthy person makes when walking. And such training of the trunk cannot be achieved by any other motor methods of treatment.

In this study, it was found that the professional rider's results exceeded the results of the non-professional rider by many times. Fixed pelvis and well-adjusted saddle allow the rider to avoid injuries and feel more conveniently, productively, and accurately. The rider should keep the pelvis in a neutral position without any rotation to avoid lumbar lordosis or anteriorly rotated pelvis. It is very essential to the rider to pay attention to the kinematic, especially, the position of the pelvis during riding and horse. Scientifically proven, that professional riders keep their pelvis closer to the centre of the saddle and further forward then non-professional riders, which tilt pelvis to the left or right and more backward. The wrong position in the saddle leads to the asymmetry in hip external rotation and back. All the movements that a rider receives from the horse are absorbed mostly by the lower region of the body such as the pelvis and hip joints. If the rider loss any mobility at the pelvis region, then all force from the horse’s movements will transfer to the lumbo-pelvic region. Incorrect absorption of movements can cause injuries in the upper part of the body, especially back injuries as it is the most vulnerable area. The rider should keep the pelvis in a neutral position without any rotation to avoid lumbar lordosis or anteriorly rotated pelvis.

This study, additionally, investigates electroencephalography of the brain activity while riding a horseback simulator. Low and high frequencies affect to the brain activity in a different range. Low frequency corresponds to relaxation and sleeping time, while high frequency is responsible for awaking time and activities such as sport, mathematics, concentration. Thus, every brain lobe represents different brain activity. While horseback riding mostly frontal lobe is active, that refers to concentration, body movements and intelligence that are needed during riding. Also, temporal and parietal lobes are highlighted that relates to sensor-motor cortex and moving.

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