‘Walking on two legs is difficult’

Robot experts learn a lot from the human body, like, for example, how to walk without falling over or wasting energy. Research being conducted at the Delft Biorobotics Laboratory also contributes to a better understanding of how we humans walk. Dr Ir. Daan Hobbelen: “Dynamically, the walking human is an unstable system.”

Saar Slegers

One robot has a Tupperware bowl for a head, the other a small blue bucket. The heads don’t really serve a practical purpose. In fact, the only reason these robots are fitted with heads is to make them look a little more like people. “A robot with just arms, legs, and a torso looks funny. It’s just not right,” Daan Hobbelen of the Delft Biorobotics Laboratory explains. “It’s important for a machine to have a head in order to evoke associations with the way humans walk, but in view of the mechanical nature of the machine, we didn’t want to add a realistic head. That could easily become scary.”

The robots Hobbelen is working on are far from scary. They are stilted figures with silly heads, and once they are switched on, they seem funny, not frightening. The website of the biorobotics lab features films of some of these robots walking, with their researchers walking alongside. Whereas the robots march blindly through the hall, the researcher, like a protective mother hen, is constantly on the lookout for edges of furniture and other hazards. Of course learning to walk involves standing and falling over; it’s just that with robots the falling over part can be very expensive.

The robots Hobbelen developed during his doctoral research are named Meta and Flame. Meta doesn’t look particularly human. The robot is a kind of cephalopod, a control system with four legs, two of which prevent the machine from falling over sideways. Meta is being used to study stability in the walking direction. Flame however has a rather more human appearance. The robot has two legs with wide, flat feet, arms, and a V-shaped upper torso. His head is shaped like the flame in the TU Delft logo. At first glance Flame appears less stable than Meta, but Flame’s active ankles and hips enable it to remain upright as it walks.

Falling as you walk

As self-evident and simple as the process of walking is for humans, so complex is it to imitate the way humans walk in a robot. Researchers are still puzzling over how humans manage to maintain their balance as they walk. Hobbelen: “Walking is very difficult, because the entire time you’re standing on one foot only. This means that you’re actually continuously in the process of falling over, unless you’re actively trying to stay upright. Dynamically, a walking human is an unstable system.” At the biorobotics lab, Hobbelen and his colleagues are trying to get a better understanding of how people nevertheless manage to remain upright.

Why would a mechanical engineer bother with the physics of the human body? Surely there are enough motion scientists and physicists better suited for the job? Hobbelen: “There are two ways to gain insight into the way humans walk. The first and most commonly used way is to measure people as they walk. You can learn a lot from this; for example, you can measure at what point people in motion tense their muscles, and you can record their movements using cameras. The problem with this analytical method is that it’s difficult to distil from these data exactly what is going on inside the body. People use lots of muscles and tendons and go through lots of motions as they walk. Body measurements are practically useless when it comes to determining what makes people, as a whole, stable as they walk.”

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At the biorobotics lab, researchers are taking another approach to studying the motion of walking. Instead of analysing it, they are reconstructing the motion. Using the simplest possible models, they are trying to determine which factors make for a stable, human walking motion. The advantage of this synthetic approach is that it is possible to vary the parameters. Joints can be made stiffer or loosened, and the power output of the control system can be adjusted. According to Hobbelen, the various types of research complement each other nicely: “Based on the results of our research, we will formulate hypotheses that can then be tested by motion researchers. And then we, in turn, will go to work using their observations.”

The contacts between the various disciplines are growing rapidly. The biorobotics lab is currently collaborating with the medical rehabilitation department of the Vrije University Medical Centre, Amsterdam, in a research project on stability during walking. Hobbelen: “We adapt our simulation models for the motion scientists’ research, and help them make the calculations. We then conduct the practical tests on our robots, using the knowledge they’ve gained from these simulations.”

**Robot-like**

Meta and Flame aren’t the first walking robots. Who hasn’t seen images of Asimo, the robot created by Honda to look like the Michelin Man? Not only does Asimo walk, run and climb stairs, he can also serve drinks, play soccer, and look around. The Honda website also states that the robot can help teach schoolchildren how to cross the street, and that he also performs daily in his own live show at Disneyland. What can Hobbelen’s robots do that Asimo can’t? Hobbelen: “Honda uses very advanced technologies. What they can make their robots do is absolutely impressive, but the control mechanism of those robots is based entirely on control technology and technological know-how. It has very little to do with what people actually do.”

The movements of a robot like Asimo are always fully under control, and the system is designed to be continuously locally stable. In order to ensure this local stability, for each step it takes, the robot first establishes firm ground contact with its foot and then proceeds to stabilise its body over that foot, using conventional control mechanics. To ensure it can stabilise itself, the robot always walks and stands with its knees slightly bent, which allows it to adjust its posture in any direction, should its position be disturbed. The way in which the robot is stabilised introduces many restrictions. The robot uses a lot of power and its range of movement is limited. And even such an advanced robot is limited in the ways it can handle interference. There is a considerable risk that an unexpected step will cause it to fall over. The way the robot walks doesn’t really look very natural, either. “People describe the way robots like this move as wooden or robot-like,” Hobbelen says. “The robots we make walk more smoothly. Their walking motion is more human-like, and that is exactly what we’re trying to do: create a robot that walks exactly like a human being.”

**Dynamic walkers**

Unlike the walking motion of fully controlled robots, a relatively large part of the human walk is uncontrolled. As we walk, our legs go through a natural pendulum motion. Maintaining this pendulum motion requires very little energy, because for most part our legs keep themselves in motion.

Hobbelen demonstrates this principle, known as a ballistic walk, using a passive dynamic walker, a robot that goes through a walking motion without any control mechanism. Hobbelen positions the robot at the top of a slope and lightly pushes it in the back.

‘Our aim is to make the robot walk exactly like a human’
Gravity gives the device sufficient energy to move forward – the robot goes from one foot onto the other, as it were, until it reaches the bottom of the slope. The natural pendulum motion of the legs not only renders walking a low-energy process, but also increases the stability during the walking motion. Whenever a passive dynamic walker is about to fall over because it is moving too fast, its foot hits the surface with greater impact, automatically reducing its speed. The natural frequency of the pendulum motion is restored within a few paces, and the robot stabilises itself. “One of the major lessons we learnt from the passive dynamic walking process is that a robot can perform a stable walking motion without having to be locally stable at every point in time,” Hobbelen says. The walker’s movements are partly uncontrolled, but the natural dynamics of the system automatically restore mild disruptions to the motion over a number of steps. In his doctoral thesis, Hobbelen named this principle limit cycle walking: “Although many researchers are working on this concept, nobody so far had analysed and defined it as such.”

Hobbelen, in collaboration with Dr Ir. Martijn Wisse and Ir. Jan van Frankenhuyzen, developed the prototypes Meta and Flame to further research the principle of limit cycle walking. Hobbelen: “Passive dynamic walkers are of some interest, but in order to render a robot’s walking motion closer to that of a human being, the robot needs to be controlled to a certain degree. People also use muscles to move and maintain their stability. If we fit the robots with extra means of control, they will be better able to cope with sudden disruptions, and they will become capable of varying their walking speed.” Adding the control systems is a step-by-step process. The preferred option is to keep the control elements in the robots as simple and as local as possible. “It is not our intention to turn it into a super intelligent computer, because that would defeat the purpose. We want to stabilise a machine with the least possible means.” Meta and Flame are the successors of another robot, Denise, which Martijn Wisse developed in 2005. Whereas the control systems in Denise were limited to the hips, Meta also features ankle controls. Flame has both ankle and upper torso controls.

**A small step**

Hobbelen studied how to improve forward and sideways stability by means of control systems located in the ankles and upper torso. For this purpose, he confronted the Meta prototype with...
unexpected downward steps, and then studied the
effect of the disruption. If a person fails to see such a
step, they will probably stumble. If the height of the
step is about ten centimetres, chances are that they
will be unable to recover. Meta currently manages to
remain stable after a three-centimetre misstep. This
may seem a minor accomplishment, but scaling the
step to human measurements brings it up to the
equivalent of a five or six centimetre misstep. “In
robotics, that is quite an achievement,” Hobbelen
proudly states. The main advantage of the controlled
robots used by Hobbelen is their versatility. “Passive
devices either work or they don’t. These prototypes
form a research platform: they allow you to make
studies of various aspects of the walking process.”
Hobbelen may have completed his doctoral research,
but that doesn’t mean that Meta and Flame can now
retire: “We have another whole series of experiments
planned.”

Stiff ankles

“What do our ankles do when we walk?” This is the ques-
tion that occupies the minds of both clinical researchers
and robot experts. By combining walk analysis and walk
synthesis, researchers hope to find answers to the ques-
tions they share.
When human beings walk, they derive a lot of power from
their ankles. As the calf muscles contract, extra energy is
generated, and the tendons act like springs for the ankles.
With each step, energy is absorbed and stored, and then
released as we push ourselves forward. People who have
an ankle dysfunction – possibly resulting from a brain
infarction, multiple sclerosis, or partial paraplegia – have
a reduced ankle power generating capability, which makes
it much more difficult for them to walk. Such patients are
often prescribed elastic ankle-foot orthoses (externally
worn ankle supports) to compensate for the reduced push-
off power.
Daan Bregman, a doctoral student at the Vrije University
Medical Centre, Amsterdam, is conducting research on
the properties of ankle-foot-orthoses. “When you fit a
patient with an orthosis, the big question is how stiff the
spring must be to provide the best support for the specific
patient,” Bregman says. Determining the optimum degree
of stiffness is easier said than done, however. “Currently,
measuring a patient for an orthosis is largely a question of
experience. The physician and the orthopaedic fitter toge-
ther determine what properties the orthosis should have,”
Bregman explains. “That the current method leaves room
for improvement is shown by the fact that many patients
do not wear their orthosis. We simply lack the objective
data needed to fit a patient with a made-to-measure
orthosis.”
It is very difficult to use walk analysis for determining the
optimum stiffness of an orthosis. It takes time for people
to get used to an orthosis, and, moreover, quite a burden is
placed on the patient. It also costs a lot of money to build
different made-to-measure orthoses for just one patient.
To gain insight into the relationship between ankle stiffness
and length of stride, walking speed, and energy consump-
tion, Bregman used walk simulations developed in colla-
boration with the Delft Biorobotics Laboratory. Bregman:
“These allow us to easily vary the parameters and study how
this affects the stride length and walking speed,” Bregman
says. “The underlying models we use for this purpose are
the same as the ones used for the robots.”
It will take a while before patients can be fitted with fully
customised orthoses. Bregman: “The ideal situation would
be one in which we collect a patient’s data by means of
walk analysis, determine the patient’s deficiency based on
this data, and then use the results to create an orthosis that
compensates for exactly that deficiency.” Unfortunately,
human ankles don’t lend themselves to tinkering as readily
as those of Meta and Flame.